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AGRICULTURAL CHEMISTRY

A Familiar Explanation

OF THE

CHEMICAL PRINCIPLES INVOLVED IN THE OPERATIONS OF THE FARM.

BY

ALFRED SIBSON,

First Assistant in the Laboratory of the Royal Agricultural College, Cirencester.

WITH A PREFACE

BY

DR. AUGUSTUS VOELCKER,

Consulting Chemist to the Royal Agricultural Society, and Professor of Chemistry in the Royal Agricultural College, Cirencester.

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PREFACE.

Although we possess several excellent works on Agricultural Chemistry, I have long felt the want of a treatise sufficiently comprehensive, and at the same time sufficiently explicit and correct, to be put with advantage into the hands of a person ignorant of the first chemical principles, and unaccustomed to scientific language. This want, I think, will be supplied by Mr. Sibson's treatise.

There are several excellent works which, like "Johnston's Agricultural Chemistry," would render a new treatise on Agricultural Chemistry superfluous if they embodied all the recent chemico-agricultural discoveries, and could be obtained at a price sufficiently low to secure an extensive circulation. There are other meritorious works on Agricultural Chemistry, which are written by authors who evidently in great measure are unacquainted with the practical wants of persons interested in farming pursuits.

Mr. Sibson's treatise certainly possesses the merit of being written by a gentleman who for several years has resided in the country, and has had many opportunities of becoming personally acquainted with the wants of the farmer, and has taken an active part in several important investigations that have been carried on in my laboratory. Mr. Sibson also has had extensive experience for noticing the peculiar difficulties that present themselves to the unscientific reader of works on Agricultural Chemistry. I believe, also, the natural arrangement of the subject-matter in the treatise,—an arrangement which is fully explained in the first introductory chapter, will be found as novel as it is practically useful, and conscientiously recommend Mr. Sibson's work to the considerate notice of the public.

AUGUSTUS VOELCKER.

Royal Agricultural College,
Cirencester, *Sept.* 1858.

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AGRICULTURAL CHEMISTRY.

CHAPTER I.

INTRODUCTION.

AMONGST the causes that have led to the present advanced position of the agriculture of this country, not the least prominent is the assistance agriculture has received at the hands of Science. While nearly every branch of Natural Science has more or less contributed to the general improvement of agriculture, Chemistry, undoubtedly, occupies a high rank amongst the means that have helped to advance this most important branch of human industry.

As it is the peculiar province of Chemistry to teach us the composition of all earthly objects, to make us acquainted with the materials of which they are composed, and the changes these materials undergo when exposed to different influences, it is not surprising that Chemistry, of all other natural sciences, is the one most concerned in the operations of daily life, or is the one most capable of affording information on all points connected with the natural and artificial changes constantly proceeding in all the materials of the earth. And as Chemistry is ever ready to impart, when properly solicited, any amount of this kind of knowledge, it cannot be wondered that nearly every branch of human industry has at different times received benefit from the hints and suggestions of this most useful and practical science.

Agriculture is peculiarly susceptible of improvement from Chemistry, inasmuch as many of the practical operations performed by the farmer are essentially chemical processes; and at the present time, when the use of artificial manures is nearly indispensable in the farm routine, a knowledge of at least the general principles of Chemistry is almost imperative in the farmer who expects to avail himself of all the appliances of modern agriculture.

Amongst the numerous contributions of Chemistry to agriculture, perhaps the most important is the introduction of artificial manures into the system of cultivation; and were this the only practical service conferred by Chemistry, it would, on this account alone, be entitled to a high place in our estimation; since it is to an extended use of these materials that we must chiefly look for the means of increasing the produce of the land, to meet the wants of a constantly multiplying population. Not only does Chemistry teach us the best means of preparing and applying these important fertilizing agents, but it points out to us sources of them which we should otherwise have entirely overlooked. At the present time we manufacture valuable manures from substances that formerly would never have been dreamt of as sources of fertilizing materials. For instance, there are found, in certain localities, beds of minerals, resembling, in their external properties, those of ordinary rocks and stones; but by chemical analysis they are found to contain a compound called by chemists phosphoric acid: this compound is an essential constituent of nearly all kinds of cultivated produce. In grain, roots, hay, &c., we find considerable quantities of phosphoric acid, which has been derived from the soil on which this produce has been raised. The soil always contains phosphoric acid, but often in deficient quantity: we endeavour to increase the quantity by adding manures, most of which contain this substance in greater or less abundance. On the discovery of the presence of phosphoric acid in the minerals above noticed, the thought

would naturally occur to us to make use of them as a source of this valuable fertilizing compound. But a difficulty presents itself: it is also found that the phosphoric acid occurring in these minerals, exists in an insoluble stony form, utterly incapable of being assimilated by the delicate roots of plants. Hence its addition in this form to the soil is followed by no good result.

But here Chemistry again comes to our assistance; it not only leads us to discover an unexpected source of a scarce material, but further directs how to proceed in changing the insoluble useless form in which we find it into a state that will admit of its use as manure. By following these directions the difficulty is overcome, and we are able to prepare a valuable manure from useless stones. The minerals we allude to are called apatite, phosphorite, coprolite, &c., and at the present time are largely employed as the raw material from which the well-known manure called superphosphate of lime is prepared. With nearly every other point of agricultural economy chemical principles are more or less intimately connected. Hence, by understanding these principles, the practical man will often be able to act with certainty in cases where, otherwise, having no rule to guide him, he can proceed only with hesitation.

Amongst the numerous branches into which the science of Chemistry has necessarily become divided by its rapid extension during the present century, Agricultural Chemistry is undoubtedly amongst the most important, and at the present time is certainly one of the most active and flourishing of these divisions. As in the economy of manufactures the division of labour is found to be so conducive to a high state of excellence of the manufactured produce, so, in the science of Chemistry, its marvellous extension during the present and two or three preceding generations, is chiefly to be attributed to the fact of each of its divisions having been taken up by particular chemists, who, by directing their energies to that portion of the subject best suited to their tastes,

have raised it to a high degree of excellence, and thus have contributed to the enlargement of the mass of knowledge at present comprised under the head of General Chemistry. At the present time several distinguished chemists are satisfied to devote the best of their energies to the subject of Agricultural Chemistry, which, in so far as its connection with the general welfare of the community is concerned, apart from its intrinsic merits, is certainly one of the finest of human pursuits.

As most of the operations of agriculture are an extension or adaptation of those of Nature, it follows that all the chemical changes involved in the phenomena of germination, growth, development of seeds, and final decay of plants, as well as the more important changes belonging to animal life, must be included in the Chemistry of Agriculture. This subject will also include the changes that accompany the alteration in the quality of land, either for the worse, by exhaustion or mismanagement, or for the better, as in the reclamation of waste lands and the restoration of those whose fertility has become impaired by culture.

To every one who takes an interest in the operations of nature, the development of every sort of agricultural produce in our fields and homesteads must be a source of wonder and delight. For instance, what can be more interesting than the growth of a wheat crop? We see the seed placed in the ground; in a short time young plants appear above the surface; the seed that had been preserved so long in an inactive state, when exposed to the influence of moisture, warmth, and air in the soil, germinates; or, in other words, the spark of vitality that had lain dormant so long in the seed, is awakened, and expends its first efforts in the production of an infant plant, which, so soon as it reaches the daylight, is able to provide for itself, and collect the requisite food for its future nourishment from the surrounding air and soil. By the imperceptible yet rapid increase of substance, the crop

acquires strength and vigour, produces blossoms, and finally seeds, which duly ripen and wait to be gathered. What can be more beautiful than a field of wheat in this condition? Every one must admire such a scene, whether he regard it as a natural object of great beauty, or as the source of our daily bread.

In contemplating such a scene, we naturally reflect on the composition and origin of the produce before us. We know that the grain of wheat contains flour, which, when properly prepared, will become bread, capable of nourishing and strengthening our bodies. Whence comes this flour? The plants have gradually increased in substance from the period when they first appeared above the ground, and have fully developed their seeds or grains, but whence has been derived the necessary material? It must obviously come from the earth, or the air, or the moisture, or from each of these sources; but what marvellous changes must take place before these materials can become the vegetable produce in question. Such a scene has an additional interest to the farmer, who, looking upon the crop as the means by which he is to pay his rent and remunerate himself for the labour and anxiety expended in its cultivation, and that of several preceding crops, will reflect more deeply than the casual observer on the circumstances connected with its growth. He knows that the produce before him has been chiefly produced at the expense of the soil. That some essential constituents have been directly obtained from the soil is evidenced by the well-known fact that the soil will require manure and rest before it can produce such another crop. But even the farmer, although better acquainted with the practical details of the matter, if unacquainted with Chemistry, is equally at a loss to account for the changes proceeding in the materials under his hands; he cannot tell what the wheat removes from the soil, and why it should not grow with equal vigour in the same field a second year, or why a crop of another kind will. Again, he cannot explain the action of the manure he uses, what

it is in the manure that imparts fertility to a soil; and why one kind of manure more particularly benefits one kind of crop. Further, it is well known that particular soils, irrespective of their general fertility, are best fitted for the growth of certain kinds of crops; for instance, clover, pease, and plants belonging to the tribe called leguminous plants, flourish most luxuriantly on lime soils, and languish, or even refuse to grow, in soils deficient in lime. Again, clay soils are known to be most favourable to the growth of wheat.

On these and numerous other points connected with the economy of agriculture, Chemistry is able to enlighten us, and in most cases to afford us a clear explanation of the changes attending the various operations going forward on the farm, as well as of the principles that regulate those changes. It will tell us, for instance, the composition of the wheat-plant, and point out the constituents of its seeds on which their nutritive value depends. It will also show us the sources of those constituents, and enable us to perceive how the presence of certain bodies in the soil affects the growth of the crop.

At the same time we must not fall into the error of expecting too much from Chemistry; it must be borne in mind that Agricultural Chemistry is yet but a comparatively new science, and many of its regions are at present unexplored. Moreover, there are matters connected with the simplest operations of nature far beyond the power of science to explain: such matters will probably ever remain as at present, profound mysteries to us.

While Chemistry makes us acquainted with the character of the materials of which all earthly objects are made, and teaches us the laws that regulate the movements of these materials, she does not for a moment attempt to explain or account for these laws; but by pointing them out to us and exhibiting their effects, she greatly aids us in comprehending the part they perform in nature.

With a knowledge of Chemistry we are better able to

appreciate the grandeur of those natural laws which, having been established at the creation by an all-wise Providence, control the movements of all the materials of the earth and insure their co-operation in the series of changes necessary for the preservation of the system of Nature.

To describe in a familiar manner the more important chemical principles involved in the operations of agriculture is the object of this little book. In doing this we have thought it advisable to begin by explaining the more striking points of what may be called the Chemistry of Nature, or that division of the subject which treats of the properties and uses of those materials of the earth which take part in the growth of plants and the nourishment of animals, whether growing in a wild or natural state, or reared and cultivated by man in the practice of agriculture.

We therefore first call attention to the atmosphere; then to the earth or soil; next to water, pointing out the respective constituents of each of those natural groups of substances, and briefly describe their more prominent characters, dwelling more particularly on those most concerned in the practical operations of the farm. We next trace the formation in the organization of the plant from materials derived from the earth, air, and water, of those vegetable compounds which afterwards become the food of man and animals. Before proceeding to explain the further changes these compounds undergo in the bodies of animals when consumed as food, we give an exposition of the changes accompanying the various operations employed in agriculture for the improvement or alteration of the texture and quality of the land, whether by mechanical or chemical means. In this division, referring more strictly to the Chemistry of Agriculture, we propose to introduce the important subject of manures, to describe the characteristic properties of natural or home-made farmyard manure, as well as the more numerous "artificials." Amongst the artificials we

specially notice bone-dust, guano, superphosphate of lime, and a few other artificial manures commonly employed by the farmer. We propose to point out their several uses, modes of application, and the qualities that affect their value; also their comparative merits, and the adulterations to which they are subject. Farmyard manure, in consideration of its superior importance, is treated at greater length, and the chemical changes this manure undergoes by different modes of treatment, described somewhat in detail. Many of the facts mentioned in connection with farmyard manure are quite new, having been but recently discovered, and up to the present time have been published only in the papers referred to in the chapter devoted to this subject.

We afterwards notice the more striking characters of all the ordinary cultivated crops, and the circumstances that affect their growth. Finally, we trace the conversion of vegetable food into the more highly organized animal products, such as butter, cheese, mutton, beef, &c.

CHAPTER II.

THE ATMOSPHERE.

Physical Properties of the Atmosphere.

THE atmosphere being invisible, most men naturally know much less of the general characters of the air than they do of the earth, water, and other more material parts of the globe. With the exception of the disturbed condition of the air that we call wind, it possesses no positive quality that compels us to recognize its presence, as we do that of the earth and other natural objects, which make themselves known to us through the

sense of sight; but since the air cannot be recognized by our sight, we are unable to judge of its qualities by any of the ordinary means of comparison.

We are however made aware of the presence of the air when its effects are exhibited to us in some of the simple occurrences of everyday life; as for instance, when we make use of a pair of bellows to urge a fire, or move a fan backwards and forwards, and in a still more striking manner when we encounter a high wind: in each of these cases the resistance we meet with plainly convinces us of the substantial quality of the air. Again, on filling a bottle with water by dipping it under the surface, we notice that the water does not enter the bottle until the air has escaped in a series of bubbles; or if we hold the bottle perpendicularly with its mouth downwards, and in this position immerse it under the surface of the water, the water will not enter, simply because the space in the bottle is already occupied with air; and in this case the air cannot escape to make room for the water, as it usually does.

By these and numerous other simple operations we may satisfy ourselves that the air is indeed a substance, notwithstanding it is an invisible one.

The air or atmosphere forms a layer of light matter immediately above, and resting upon the solid surface of the earth. In this light matter we, and every object we look upon, are immersed: it envelops us on every side, and fills every space that in common language is said to be empty. Before proceeding to state of what this matter consists, or the part it performs in the economy of nature, let us briefly relate its physical or mechanical properties.

The air is a transparent, invisible substance, destitute of taste and smell, and permanently elastic, and movable in every direction. Viewed in masses, it possesses a slight blue colour: the beautiful blue tint that often pervades the further objects in a landscape, is due to this colour of the air.

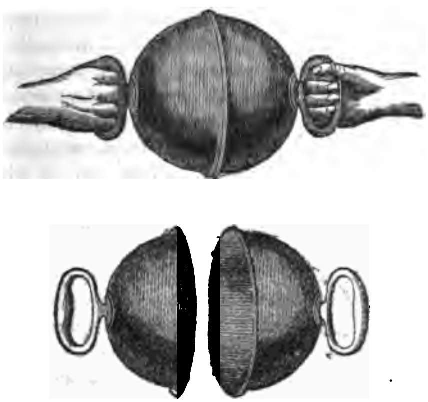
Since the air is a substance, it follows it must also possess weight. This is found to be the case. By suitable instruments the air can be weighed, and its weight determined. A cubic foot of air weighs 527 grains, or about an ounce and a quarter, or is 715 times lighter than water. Now as the air extends upwards to a great height, and every part of it possesses weight, it is evident that it must press upon the earth with considerable force. This force or weight can also be determined, and the entire weight of the atmosphere ascertained. The air presses upon the whole surface of the earth with as much force as would be exerted by a covering of water thirty-two feet deep, or a layer of quicksilver about thirty inches deep. Hence, a column of air of the entire height of the atmosphere, that is, from the surface of the earth to as far upwards as it extends, weighs the same as a column of water of the same size but only thirty-two feet high, or a column of quicksilver only thirty inches high. The actual weight of the atmosphere, or the force with which it presses upon the earth's surface, is about 15 lb. on every square inch. The reason we do not feel this weight is because of the property of the air, called its "mobility," or the power of its particles to move in any direction. By this provision the downward pressure, or weight of the air, is diverted and distributed over every side and on every part of the objects exposed to it; for instance, the weight pressing down upon our bodies is sustained by a corresponding weight pressing upwards, and the weight pressing upon one side of us is counterbalanced by the air pressing with an equal force on the opposite side. For this reason we remain perfectly unconscious of this prodigious weight of the atmosphere; it is, however, instantly displayed, if by any means the air is removed from one side of an object, when the full weight of the air is exerted on the opposite side.

Several interesting experiments can be shown for proving the weight of the air; but since an entire division of natural science, called Pneumatics, is devoted to this

subject, we need not enter any further into the physical properties of the air.*

In conclusion we may remark that several useful instruments in daily use depend for their action upon the weight of the air; for instance, the lift-pump and the barometer, or weather-glass, are instruments of this sort. The latter particularly deserves notice, since, in addition to its being a most valuable instrument to the farmer, mariner, and others, whose prosperity is often influenced

* We must, however, describe one simple experiment, that in a most striking manner exhibits the weight of the air. A hollow brass globe of about six inches in diameter, is made in two pieces that fit accurately together: each piece is provided with a handle attached to its centre. These two hemispheres can be taken apart at pleasure, and are not fastened together in any way; if, however, the two halves are put together, and the air removed from the interior of the globe, by means of a stopcock, not shown in the figure, the weight of the atmosphere is exerted upon the outside, and the two halves are firmly pressed together with such force that two men are unable to pull them apart.



This experiment excited a great amount of admiration when first exhibited by its inventor, Otto von Guericke, at Rendsburg, in Germany, in the year 1680.

by the weather, it affords us the best proof of the weight of the air; it also shows the slight variations to which this weight is subject; and as these variations are indicative of certain atmospherical phenomena, as wind, rain, &c., its action as a foreteller of the weather is explained.

The Materials of which the Atmosphere is composed.

Having shown by the above statements that the air is a substance, we now proceed to consider what kind of substance it is, what materials it is composed of, and the connection between these materials and animal and vegetable life. We propose to do this in as simple a manner as possible, and to leave out all scientific terms and expressions, except those which, having no familiar substitutes, we are obliged to make use of.

All the materials found in the air belong to a class of substances called gases. The air, then, is a mixture of gases. Let us begin by explaining what a gas is. All the materials belonging to our globe are either solids, liquids, or gases. This latter class of bodies is sometimes subdivided into gases and vapours, but in reality there is no essential difference between a gas and a vapour; so that we may consider all materials of which the various natural objects are made, to belong to one or other of these three classes. Every one naturally becomes acquainted with a great number of the solids and several of the liquids belonging to the earth, but comparatively few of us are acquainted with the different gases of the earth. This is because solids and liquids make themselves known to us through the sense of sight. The differences between them are easily perceived, and we instinctively recognize their individual characters. But the case is different with gases. Although the number of gases is large, few of us are acquainted with any of them. It is because their individual characters are not so strikingly displayed as those of the more material solids and liquids, and, consequently, we cannot by our unaided senses distinguish between them. All gases resemble more or less the air we breathe. They

are all transparent, and all very much lighter than either solids or liquids. Yet the differences amongst themselves are very great in their appearance and qualities; and especially in their chemical characters they differ most widely. For instance, while the majority of gases are colourless and invisible, some of them possess beautiful colours. There is a green gas, a red gas, and a violet-coloured gas. Many of them are inodorous, others possess pungent smells; others again abominable and poisonous odours. While some of the gases are much heavier than the air, a few are considerably lighter. Thus we perceive there is almost as great a variety even in the physical properties of gases as there is in those of the more substantial solids and liquids.

Further, there are two great classes of gases :—

1. Simple or elementary gases; *i. e.* airiform substances that consist of one kind of matter only.

2. Compound gases, or airiform bodies consisting of several materials, into which they may be separated by suitable means.

The number of gases known to chemists is very great; but, fortunately for those persons who take an interest in the materials of the earth only in so far as their connection with animal and vegetable life is concerned, only few gases have to be noticed. Usually not more than five or six gases are found in a free or uncombined state. And here we may remark, that most gases are not a class of bodies permanently different from the solids and liquids of the earth. A gas must be regarded as a peculiar shape, —a greatly expanded, enlarged condition, that certain bodies have the power of assuming under peculiar circumstances.

It need scarcely be repeated that all the gases usually found in the air are devoid of taste, colour, and smell, and are transparent and invisible. The atmosphere consists chiefly of two gases, called respectively oxygen and nitrogen. These two gases form the bulk of the air; all the other constituents occupying but a small space of the air. Of these two gases nitrogen is the more abundant,

forming four parts out of every five : the remaining fifth is oxygen. The other constituents are carbonic acid gas, water in the form of gas or vapour, with much smaller and varying quantities of nitric acid and ammonia.

The composition of the atmosphere may thus be stated—

COMPOSITION OF THE ATMOSPHERE.

(One Hundred Parts.)

	By Weight.	By Measure.
Oxygen	23·3	21
Nitrogen	76·7	79
	100·0	100

Carbonic Acid in 10,000 parts of Air.

Largest quantity ..	5·74
Smallest quantity ..	3·15

Water in 100 parts of Air at—

	Parts of Water.
30 deg. of thermometer	·41
50 " "	·80
80 " "	2·01
90 " "	2·70
100 " "	3·60

We now proceed to describe each of these constituents, its qualities, and the part it performs in nature.

Properties of Oxygen.

Oxygen is the most abundant material of the earth. It not only forms, as we have seen, one-fifth part of the entire atmosphere, but it forms a still larger proportion of the bulk of water, rocks, earths, and minerals. In water, eight parts of every nine are oxygen,—the vast quantity of water on the globe, in the shape of seas, rivers, lakes, and the great oceans themselves, all containing oxygen in this proportion. Again, in rocks, minerals, and soils, oxygen forms a large proportion, averaging about one-half of their weight; thus one-half of all the rocks and solid materials of the globe consists of oxygen. It is no less abundant in the animated world. In animals, oxygen forms three-fourths of their weight; in vegetables, four parts out of every five consist of oxygen. Thus we see oxygen is the chief material

of which the entire globe is made. We also learn by the above statements, that oxygen exists in three different mechanical forms: as a liquid in water; as a solid in rocks, stones, and soils; and in a state of gas in the air. In this latter condition it is free or uncombined; and in this form we shall now describe it.

Oxygen gas is the active principle of the air. Most of the properties we usually ascribe to the air are, in reality, due to the oxygen it contains. For instance, we say that a fire or a candle will not burn without air; but it is the oxygen only of the air that the fire or candle requires. Again, animals are said to require air in the vital process of breathing; but it is the oxygen only that takes any part in the operation. On exposure to the air, metals—as iron, zinc, &c.—are known to get corroded or rusted. Here, again, it is the oxygen that corrodes or rusts them. And so, in most natural operations, it is the oxygen that induces the changes observed to follow exposure to the air.

Oxygen in a pure state closely resembles the air in its external properties: it is equally colourless and free of smell; it is characterized by possessing all the chemical properties of the air in a much higher degree. In other words, everything that the air does, oxygen does far more quickly and violently. In air, iron rusts slowly and imperceptibly; in oxygen, it rusts with such violence that in a few seconds a piece of iron is entirely converted into rust. Brimstone, that burns in the air with a pale blue flame, scarcely visible by daylight, in oxygen burns with a brilliant light. A candle recently blown out, is re-lighted, if placed in oxygen gas. In fact, every material that burns in the air burns with increased brilliancy and violence in oxygen. Oxygen acts in a similar manner on animal life, the process of breathing being hastened to such an excessive degree as to produce death.

The effects of combustion, respiration, rusting of iron, &c., either in pure oxygen or in the air, are produced by the oxygen combining with the materials concerned.

in the operation. Wherever a fire is seen, the oxygen is combining with the fuel; when iron is converted into rust, the oxygen combines with the metal. Thus the distinguishing property of free or uncombined oxygen is its affinity, as chemists say, or its inclination, if the term may be used, to combine with all bodies in a condition to receive it. The phenomena of combustion, respiration, decay, putrefaction, &c., are all consequences of this property of oxygen; and in all these operations compounds of oxygen are formed. These compounds are called by chemists oxides. These oxides are very abundant in nature: thus all the materials belonging to the soil, as sand, lime, &c., are mixtures of oxides, or consist of oxygen gas combined with various other subtances.

Properties of Nitrogen.

The too exciting oxygen is diluted and its activity properly restrained by the more abundant but indifferent substance nitrogen. As we have seen, four parts out of every five parts of air consist of nitrogen: hence, there is an enormous quantity of nitrogen on the globe; but, unlike oxygen, its presence is almost confined to the atmosphere and the animal and vegetable kingdoms, and seems to form but a small part of the mineral portion of the earth.

Nitrogen in a pure state cannot be distinguished by our unaided senses from common air, or even oxygen; it is equally devoid of all striking qualities when in a separate or unmixed condition. It differs from oxygen in its effects upon burning bodies: oxygen, as we have seen, accelerates the combustion of burning bodies, as a candle or taper; nitrogen instantly extinguishes them. Hence we may readily distinguish it from oxygen, and by the same test also from the air. An animal is killed by immersion in nitrogen, not from any poisonous qualities of the gas, but simply because it deprives the animal of the indispensable oxygen: the taper is extinguished from the same cause.

Nitrogen, as found in the air, is remarkable for its inactive, indifferent qualities, its only purpose in this state seeming to be to curb the impetuosity of its too excitable companion—oxygen. Were we unacquainted with nitrogen in any other form, we might pronounce it to be almost destitute of chemical properties; but such would be a very unfair estimation of the characters of nitrogen, since it forms, when in combination with other bodies, compounds remarkable for the essential functions they perform in the growth of plants and the nourishment of animals. The fact is, nitrogen seldom combines directly with other substances, as oxygen does, but always does so in a roundabout manner. Hence compounds of nitrogen are not formed, when substances are exposed to it in the air, as they are of oxygen under the same circumstances.

Nitrogen in a solid form is present in all cultivated plants, as grasses, roots, wheat, &c., and particularly in those parts of the plants distinguished for their nourishing qualities when used for the food of men or animals. The grain of oats, barley, and wheat all contain nitrogen.

Also in the bodies of animals nitrogen occurs in great abundance. Animal matters of nearly all descriptions contain a large proportion of nitrogen;—in flesh, hair, feathers, bone, &c., there is a great deal of this substance. Hence the flesh of our domestic animals in the form of animal food supplies us with large quantities of this solid or combined nitrogen; indeed, most kinds of food, and particularly those sorts of food noted for their strengthening properties, contain nitrogen in large proportions; and so inseparable is the presence of nitrogen from the nourishing qualities of food of all descriptions, that the value of feeding materials depends in a great measure on the quantity of nitrogen they contain.

It must be borne in mind that the oxygen and nitrogen of the air are merely mixed together, and not chemically combined.

It is important to understand in a clear manner the distinction between a mechanical mixture and a chemical combination. In a mechanical mixture, each constituent remains unaltered in its essential characters, and may generally be recognized in the mixture by the naked eye or by a microscope, and in most cases may be removed from the mixture by mechanical means; and further, when separated, will be found in the same condition as it was before being added to the mixture. The appearance and external properties of a mixture are regulated by those of its constituents. On the contrary, in a chemical combination, or as it is called, a compound, one substance at least is essentially altered, and by no amount of examination by the naked eye or a miscroscope, can the constituent particles be detected. Hence the smallest particle is of the same quality as the bulk of the substance, the whole being perfectly uniform and homogeneous. Moreover, the qualities of compounds are not regulated by those of their constituents. Liquids may produce solids; gases may produce liquids; poisons may be formed from innoxious substances: so no opinion can be formed of the characters of a compound by judging of the qualities of its constituents. Two or three examples will render this more intelligible—When chalk is powdered and mixed with water, a creamy liquid results, possessing qualities intermediate between those of chalk and water. On standing, the chalk settles to the bottom, and the clear water is the same as before the experiment. If instead of chalk we use plaster of Paris, the creamy liquid in this case will quickly harden and finally become a solid mass; the water will disappear, and no longer be perceptible by the properties it exhibits in a liquid form. In this latter case, the materials employed have combined together chemically. Again, gunpowder is a mechanical mixture, although a most intimate one: it consists of charcoal, brimstone, and saltpetre. By washing in water, the nitre is dissolved, and now can easily be removed and separated from the two other ingredients by filtering and straining. The

nitre may be obtained in a solid form by evaporating or boiling away the clear liquid over a lamp or fire until it dries up. The other two constituents—sulphur and charcoal—may also be separated by suitable means, which need not be described here. Each constituent thus separated from gunpowder will be found in precisely the same condition, as regards its chemical characters, as before being manufactured. But as we all know, if fire is applied to gunpowder, it is instantly consumed, leaving nothing but a small residue; in other words, its constituents have combined chemically—and how different are the resulting compounds. Except a trace of solid matter, nothing but smoke is seen; yet these products, with some invisible gases, contain all the sulphur, charcoal, and nitre that existed in the gunpowder. These materials have assumed new forms, in which none of their original properties can be recognized.

Another extraordinary property of chemical compounds may be briefly noticed; viz., they always contain definite proportions of their constituents; from whatever source derived, they are invariably of the same composition, and possess the same chemical characters. For instance, the compound known as chalk, or carbonate of lime, is found to be the same material, whether obtained from chalk rocks or prepared by passing carbonic acid into limewater. In both cases the chalk is chemically identical, and consists of 22 parts of carbonic acid gas and 28 parts of lime.

It has been wisely ordered that the oxygen and nitrogen of the air shall only be mechanically mixed, and not chemically combined. Had it been ordered otherwise, or were they suddenly to combine, the entire face of nature would be altered; the bland, health-giving air would be changed into the corrosive nitric acid, or aqua fortis. The only essential difference between the air we breathe and aqua fortis is, that in the air the above gases are mixed and in the latter case combined. Marvellous as it may seem to persons unacquainted with Chemistry, it

is nevertheless true that air and the corrosive nitric acid are formed of the same materials.

We mention nitric acid, or aqua fortis, not only as a substance that might be formed from the constituents of the atmosphere, but as one that is formed, and in minute quantities is actually found in the air; while nitric acid in a concentrated form is a corrosive, destructive liquid, in a very diluted or in a modified form it is a valuable material for promoting the growth of plants. We often apply nitric acid to our crops when we use nitrate of soda (the well-known artificial manure) as a top-dressing. In this manure the nitric acid exists in a subdued, disguised form, none of its corrosive properties being displayed. In an analogous form, nitric acid is present in minute quantities in the rain that falls during thunderstorms.

It has been found that when currents of electricity are passed for a length of time through a portion of air, small quantities of nitric acid are formed, produced by the constituents of the air combining chemically together. This operation takes place on a large scale in nature, the powerful currents of electricity generated in the atmosphere, giving rise to the awful phenomena of lightning and thunder, induce the materials of the air to combine together, and nitric acid is formed. This substance again combines with another body called ammonia, also present in the air, and both together form a salt, which is called nitrate of ammonia. In this state it is conveyed to the earth and to the growing plants by the rain. Thus we see that the fresh, vigorous appearance of our crops, often noticed after thunderstorms, is due to a small dose of valuable manure they have received, in addition to the ordinary refreshing effect of the rain.

Properties of Carbonic Acid Gas.

The next constituent of the atmosphere that demands our attention is carbonic acid gas. Excepting nitric acid, we have described only the materials of the air pro-

vided for the accommodation of animals; let us now consider carbonic acid, the material especially provided for administering to the wants of plants.

Carbonic acid gas forms a comparatively small proportion of the atmosphere—about one part in every $\frac{1}{2000}$ parts of air. Small as this quantity seems in relation to the vast bulk of the atmosphere, the absolute quantity of carbonic acid gas is really immense, and sufficient for supplying the entire vegetable world with the chief material for its growth. Carbonic acid contributes to the health of plants in a manner analogous to that exerted by oxygen towards animals; in fact, carbonic acid is the source from which plants derive the greater part of their substance—they feed upon it and appropriate it as animals do food.

In a free state, carbonic acid gas possesses the following properties. It is an invisible gas, having a slight odour, and is considerably heavier than the air; it is a decided poison to animals: like nitrogen, it instantly extinguishes all burning bodies. Carbonic acid not only forms a part of the atmosphere, but in a solid state exists in rocks, minerals, and soils to a great extent. In chalk, marble, and other calcareous rocks, it forms nearly one-half of their weight; in most rocks of this description, about 22 lb. of every 50 lb. consist of carbonic acid gas.

Both the gases we have hitherto described are simple or elementary gases. Carbonic acid differs from them in being a compound gas—one that can be separated into two other materials. Carbonic acid consists of oxygen chemically combined with the solid substance carbon, or charcoal. In every 22 lb. of this gas there are 6 lb. of charcoal and 16 lb. of oxygen.

Carbonic acid gas is thus always found when oxygen combines with carbon or charcoal; and as this charcoal is the prevailing constituent of all materials used for fuel, it is clear that wherever fires are burning in grates or furnaces, enormous quantities of carbonic acid escape into the air. Carbon also forms a large proportion of

the food of animals; and by their breathing this carbon is partly converted into carbonic acid gas. Before proceeding any further, it will be well to make ourselves acquainted with the properties of carbon.

Properties of Carbon.

Carbonic acid gas, as we have seen, consists of oxygen gas chemically combined with the solid substance carbon, or charcoal. In forming this combination, the carbon and oxygen put aside the characters they possess in a separate state, and together become a new substance, possessing new properties totally distinct from those of either of its constituents. One of the constituents of carbonic acid gas—oxygen—has already been described; let us now direct our attention to carbon. In every 22 lb. of carbonic acid gas there are 6 lb. of carbon, or charcoal—we say charcoal, because this substance is the nearest approach to pure carbon. Coke, soot, coal, &c., are all varieties of carbon, of different degrees of purity. We are all familiar with the black, porous, brittle, solid charcoal, the form which carbon usually assumes when in a separate or uncombined state; it is, however, known in another and more attractive form; viz., as the precious diamond. It is a fact tolerably well known, yet none the less marvellous, that the diamond is chemically identical with charcoal. Both consist of carbon; the only difference being, that the diamond is perfectly pure carbon in a crystallized state, while charcoal is carbon said to be "amorphous," or devoid of peculiar shape. Thus we see how much the arrangement of the particles of a substance determines its external properties and appearance. Carbon, with its particles loosely arranged, with spaces or pores between them, represents black, brittle, common charcoal; the same material in a compact, dense form constitutes the transparent, hard, glittering gem, diamond. Numerous examples of this kind might be noticed. Gold and silver, for instance, when finely divided, are greyish-

brown powders, altogether devoid of the metallic lustre peculiar to these metals.

Carbon is a most abundant material of the globe, especially in the animal and vegetable kingdoms. In the bodies of animals, carbon forms a large proportion of their weight, and in vegetables a still larger proportion: about half the weight of dry wheat, hay, roots, &c., consists of carbon. Carbon occurs to a less extent in the mineral portion of the earth. In coal, graphite (the mineral of which the so-called blacklead pencils are made), limestones, chalk, marble, &c., a large proportion of carbon is present.

When wood or vegetable products are burned, their carbon, and other combustible substances they contain, are consumed; that is, the carbon combines with the oxygen of the air, and passes off as carbonic acid gas. If, however, the combustion is arrested before all the inflammable matter is burned away, the greater part of the carbon is obtained in the form of charcoal.

Charcoal, or carbon, in the black, brittle condition usually met with, is distinguished for its insoluble and imperishable qualities. A piece of charcoal buried in the earth will remain there any length of time without showing symptoms of decay. Advantage is often taken of this property of charcoal to preserve from decay timber that is buried in the earth,—as gate-posts, posts of fences, &c. By charring the surface of wood, a layer of carbon is formed, which in a great measure preserves the inclosed wood from further destruction. Another remarkable property of charcoal is its extreme porosity. On examining a piece of charcoal by a magnifying-glass, it will be found to be full of minute pores or tubes: these fine tubes absorb gases, in the same manner as a sponge does fluids. In this way charcoal is capable of absorbing and fixing large quantities of certain gases. Its power of absorbing ammonia gas is particularly large. In a dry condition, charcoal absorbs 700 times its own volume of this gas. To a less extent, but still in considerable

quantities, charcoal absorbs poisonous and disagreeably-smelling gases. Hence charcoal is a valuable disinfectant; it absorbs and retains infectious and other noxious vapours floating in the air, and may be used with much benefit as a means of purifying hospitals and other places where poisonous or contagious matters are likely to be present.

Charcoal is also capable of absorbing and removing the small quantities of putrefying animal or vegetable matters that sometimes render water unfit for domestic purposes; indeed, so active is charcoal in removing offensive and unwholesome smells and effluvia of every description, that a layer of it placed on the putrefying carcasses of animals or other offensive things, effectually prevents the escape of any unpleasant odour or poisonous emanations.

The above statements will aid us in understanding a process continually going on in our cultivated soils, and affecting in some measure their fertility.

All soils, particularly garden moulds, contain *humus*. This substance is formed from the vegetable matter left in the soil from previous crops: it resembles charcoal in many of its properties (amongst others is its colour, the dark colour of cultivated soils being due to the humus they contain), and may be regarded as charcoal resulting from the process of decay. Hence it is called sometimes humus-coal. The two substances differ in this respect; that while ordinary charcoal is almost imperishable in the soil, humus, on the contrary, undergoes a gradual destruction in the soil, the oxygen of the air uniting with it, and furnishing a supply of carbonic acid for the use of plants. The two materials are, however, so far alike, that humus also possesses, though in a less degree than charcoal, the property of absorbing gases, especially ammonia gas. In virtue of this property, the humus of the soil absorbs and retains ammonia from the atmosphere, in which it exists in minute quantities. The ammonia thus collected is supplied, through the medium of water, to the roots of plants, in whose organism it

performs the important functions that will be described in the following chapter.

The heat given off during the burning of wood, coal, and all kinds of vegetable materials, is the result of the intense chemical action between the combustible elements of the fuel (the chief of which is carbon) and the oxygen of the air. Without entering into an explanation of the nature and causes of heat, it may be taken for granted that whenever substances combine together chemically, heat is produced. In the process of burning or combustion, the combination between the combustible materials and the oxygen of the air takes place with great rapidity, and a corresponding amount of heat is liberated: this gives rise to the phenomena of fire. Fire is nothing more than a rapid liberation of heat. When the combination takes place slowly, as in the process of decay, the same amount of heat is produced; but as in this case the liberation extends over a length of time, no perceptible warmth is produced. In the process of respiration, or the breathing of animals, this combination between combustible materials and the oxygen of the air takes places in the lungs at a speed intermediate between that of combustion and decay. In this vital process, the oxidation is so regulated that an amount of heat is produced sufficient to sustain the necessary warmth of the body. Thus the process of respiration is closely allied to the operations of combustion and decay. In each case heat is produced by the oxidation of combustible materials. Further, the materials concerned in either process are the same, as are also the ultimate products of this oxidation.

These combustible materials are conveyed to the bodies of animals in the food they eat. A large proportion of most feeding materials consists of substances of this kind, which may be regarded as fuel for sustaining the animal warmth. Oil and fat, sugar and the starch of flour, are examples of this sort of food. As we shall learn in a subsequent chapter, these facts are intimately associated with the theory of feeding and fattening cattle.

The greater part of the carbon consumed in the food of man and animals is thrown off as carbonic acid gas in the breath exhaled. It is for this reason that animals require fresh air, and die if deprived of it, or when confined in a space where the vitiated air cannot escape. If we remain in a small room, where the carbonic acid gas of our breath cannot escape, it is clear we must in a short time breathe it over again; and since this gas is, as before mentioned, a poison, its inhalation must be attended with inconvenience and disturbance of health. The small proportion of carbonic acid present in the air is not felt, because we are accustomed to receive it; but any quantity larger than this normal quantity always produces effects more or less serious. Even the comparatively small quantity of carbonic acid, which exists in the atmosphere of crowded rooms, theatres, &c., produces headaches, sleepiness, and other disagreeable symptoms; but if the quantity is still larger, it produces serious derangement, and even death, as in suffocation by charcoal fumes—an accident of not unfrequent occurrence, and one that is generally caused by persons ignorant of the simplest chemical laws.

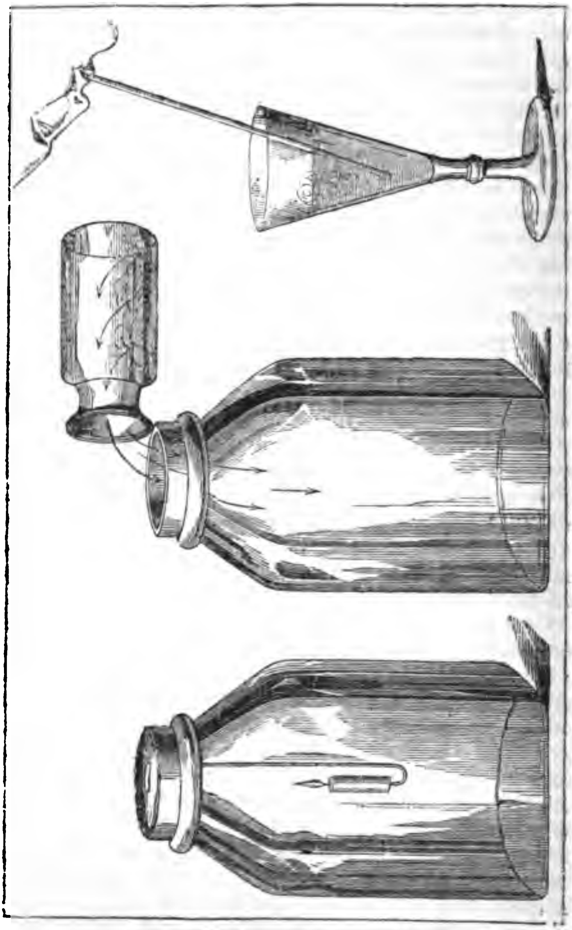
Hence we learn how necessary it is that the rooms we inhabit should be properly ventilated, or at least provided with some means of ingress and egress for the air.

That carbonic acid gas is really formed in the process of breathing, and is present in the breath we exhale, can be shown by the following simple and interesting experiment:—Whenever carbonic acid meets with lime, it forms a white substance called carbonate of lime, or, in familiar language, chalk. This fact furnishes us with a test for lime, or the means of recognizing its presence. To apply this test for carbonic acid, we use lime dissolved in water—limewater, as it is called. It is made by adding to some water, in a jug or bottle, caustic or freshly-burned lime. The muddy liquid is left at rest until the lime has settled to the bottom, and the liquid becomes

perfectly clear. The clear liquid contains lime in solution, and is called limewater. By blowing through a small glass tube, or the stem of a tobacco-pipe, into a little of this limewater contained in a wine-glass, the clear liquid becomes milky, owing to the formation of fine particles of chalk produced by the carbonic acid gas of the breath combining with the lime of the limewater.

The identity of the carbonic acid of our breath and the carbonic acid emanating from a burning candle or fire, can be demonstrated by the following experiment:—A piece of candle, or better, a wax taper, is attached to a wire, and the wire suspended from the cork of a wide-mouthed bottle (a pickle-bottle will do extremely well for the purpose). If we now light the candle or taper, place it in the bottle, and put in the cork, the taper will burn a few minutes, and afterwards go out: it will have consumed all the oxygen of the air contained in the bottle, or, in other words, will have converted all the oxygen into carbonic acid gas. On pouring into the bottle a little limewater and shaking it, a white milky substance will be observed, as in the first experiment. Further, by the same test, we may prove that marble, chalk, or limestone of any sort, contains carbonic acid gas in a fixed or solid form.

Some fragments of chalk or limestone are placed in a small bottle with a little water and some strong vinegar; or better, a little oil of vitriol, or spirits of salts, of the shops, is added. A boiling up, or effervescence, will ensue, caused by the escape of carbonic acid gas. This gas may be examined in the following manner:—A distinguishing property of carbonic acid is its great weight, compared with the air; consequently, it will flow from one vessel to the other like a fluid. By placing the bottle containing the acid and chalk in an inclined position, with its mouth near to that of another empty bottle (the bottle used in the preceding experiment will do very well, if washed out two or three times), the carbonic acid gas in the first



bottle will flow into the second, and may now be tested by adding limewater: as before, a white milky substance will be formed.

It will be noticed that the quantity of carbonic acid in the atmosphere is constantly augmented by the combustion of fuel, the breathing of animals, and the process of decay, putrefaction, &c. When we recollect the thousands of tons of coals consumed in this country alone, the multitude of animals on the globe, the millions of human beings, all pouring carbonic acid into the air, we are amazed at the prodigious quantities of this gas that must be added to the air. How is it that this gas does not accumulate to an injurious extent? What becomes of all this poisonous gas? These are questions that naturally occur to us, on becoming acquainted with the above facts. Before seeking replies to these questions, it is well to recollect that the oxygen of the air diminishes in proportion as the carbonic acid accumulates. To be more precise, every 22 pounds of carbonic acid remove 16 pounds of available oxygen from the atmosphere. Hence we must not only find out in what manner the pernicious carbonic acid is removed, but also by what means the indispensable oxygen is replaced. Both these operations are performed by plants. Plants breathe the carbonic acid gas rejected by animals, and appropriate a part of it; plants *inhale* carbonic acid; by a wonderful organization they decompose it, separate it into its original constituents—carbon or charcoal and oxygen gas. The former substance is retained as a material for adding to their growth, and building up their stems, leaves, and fruit, while the oxygen is *exhaled*, and returns to the atmosphere. Thus plants return to the air the oxygen borrowed from it by animals. At the same time animals prepare food for plants by reconverting the rejected oxygen into carbonic acid gas, which to them is a wholesome and necessary food. Thus plants and animals not only promote each other's welfare, but are actually dependent on each other for existence.

The Moisture or Water of the Atmosphere.

Let us now consider the fourth constituent of the air; viz., watery vapour, or water in the shape of invisible gas. On boiling, water passes into steam, which disappears in the air. This is because the air is capable of dissolving or taking up water in this gaseous or vaporous form. When water is exposed to the air in an open vessel, it gradually diminishes, and if left long enough, entirely dries up and disappears: in this case it also passes into the air. Every one must have noticed that the evaporation of water proceeds more rapidly in warm weather than in winter. The reason of this is: warm air dissolves or takes up a great deal more water than cold. Hence we find the proportion of water in the atmosphere constantly varying; being greater in warm weather than in cold. Evaporation takes place from all natural waters exposed to the air. From the surface of the sea, lakes, rivers, &c., water constantly rises in invisible vapour or gas, and mixes with the air. That apparently dry air—as that of a room in which we live—really contains a large quantity of water, may be proved by exposing to air substances that have a great attraction for water—"hygroscopic substances" as they are termed. A substance of this sort is well known, and may be easily procured by the name of pearl-ash. If a small quantity of pearl-ash is exposed to the air, it gets moist, and finally runs to a liquid. This change in its condition is merely induced by the water attracted from the air. If we take the trouble to weigh the substance at the time of exposure, and again after a little time, an increase of weight will be found: this additional weight is water absorbed from the air.

We cannot sufficiently appreciate the benefit we derive from this water dissolved in the air. By it the air is softened and moistened, so that the delicate organizations of plants and animals, to which the air gains access, are not injured or irritated as they would be were the air dry and totally devoid of moisture. We must all have felt

the unpleasant, and even injurious, effects of air deficient in moisture, in the bleak, cutting east winds that in this country so commonly mar the beauty of our spring months.

It is probably in the form of rain and dew that the water of the air most deserves our admiration. These beautiful phenomena, that contribute so much to our welfare and happiness, by the essential service they render in the growth of all our crops, are formed by the steam or vapour of water in the atmosphere returning to its original liquid condition.

Ammonia.

Another constituent of the atmosphere remains to be noticed, viz. ammonia, which, although it forms but a very small proportion of the air, yet contributes in no small degree to the beneficial effect of the air upon plants.

In speaking of nitrogen, it was mentioned how reluctantly and by what indirect means only, this gas combined with other gases and substances. As if to compensate for this inactive and indifferent disposition of nitrogen in a free state, its compounds, are remarkable for the essential service they render in promoting the growth of plants, and contributing to the nourishment of animals. Ammonia is one of these compounds of nitrogen ; it is one of the necessary, perhaps the most necessary material requisite for the growth of plants. It exists in minute quantities in the atmosphere, as before stated, and also forms an important part of most natural and artificial manures.

Ammonia consists of nitrogen and hydrogen (another gas that will presently be described under the head of Water), chemically combined. It possesses properties so peculiar and so different from those of its constituents, that we are sometimes led to forget its origin, and regard it as an elementary substance. Ammonia is well known by the name of hartshorn, a name probably derived from

the ancient method of preparing it by burning horn or bones in a close vessel. In a free state, ammonia is a gas, invisible and colourless, but possessed of a powerful, irritating, pungent smell. Unmixed with air, this smell is so overpowering as to be injurious and destructive to life; but when much diluted with air, is said by many persons to be agreeable and refreshing: in this diluted state ammonia is frequently used for smelling-bottles. Whenever animal matters, as horns, hair, feathers, bones, &c., are burned, the nitrogen they contain combines with the hydrogen also present, and ammonia is formed, which passes off with the smoke and other strong-smelling compounds simultaneously formed; so that the ammonia cannot be recognized by its well-known smell, but may easily be detected by suitable tests.

The same thing takes place more slowly when animal matters decay or putrefy. Another source of ammonia is coal. In all coal a little nitrogen is present: this in burning becomes ammonia. If the coal is burned in open fires, the ammonia is lost; but when coal is heated in closed vessels, as in the process of gas-making, the ammonia is usually collected by suitable means. From this source nearly all the compounds of ammonia met with in commerce are obtained.

Ammonia in a pure state, or as usually present in the air, combined with carbonic acid gas, is an extremely volatile substance; it flies off as soon as produced, and by heating is driven out of any mixture containing it. The liquid known as spirits of hartshorn is ammonia dissolved in water. It possesses properties like potash, soda, or lime. Ammonia belongs to a class of substances called alkalies; and since this is a term often employed in describing chemical changes, it may as well be explained this place. Soda, potash, lime, and ammonia resemble each other in possessing a peculiar caustic or alkaline taste—hence they are called alkalies; they also produce when handled a slippery, soapy sensation on the fingers; and, further, they all possess the power of removing or

concealing the characteristic properties of another class of bodies called acids, or sour substances; as vinegar, sulphuric acid, or oil of vitriol. Alkalies and acids are said to be antagonistic to each other, because, in combining together, they fight, so to speak, and deprive each other of their characteristic properties.

When we try to improve sour beer by adding to it soda, we avail ourselves of these properties of acids and alkalies. We find the sour taste disappears; at the same time the unpleasant taste of the soda is not perceived: the two substances have neutralized each other. The acid and the soda are still present, but all their characteristic properties are disguised.

The intensely sour acid called oil of vitriol may be neutralized in this way by soda, lime, or any other alkali. Whenever acids and alkalies thus neutralize each other, a new substance is formed, with a taste neither acid nor alkaline, but saline: hence the term salt. When soda is added to sour beer (it need scarcely be said beer becomes sour from the formation of vinegar), a salt is formed, which remains dissolved in the liquid. Ammonia is distinguished by being the only volatile alkali,—the only one that flies off by exposure or heating. This may be proved by a simple experiment, which is very instructive, inasmuch as it enables us to understand what is meant by the expression "fixing ammonia," so often used by agricultural writers. A little spirits of hartshorn, that is, a solution of ammonia in water, is boiled in a cup over a lamp. The ammonia will rapidly escape into the air, and after a short time the liquid left in the cup will have lost its pungent smell; all the ammonia will be volatilized. If we add vinegar to another portion of hartshorn until the pungent smell is overcome, and now boil this liquid as before, no ammonia will escape; it is retained by the acid, and has now become a salt: it has been fixed. We may obtain this salt in a solid form by evaporating the liquid until it dries up. The white saline mass contains all the ammonia combined with the vinegar.

Ammonia in a free state is often liberated in stables or from recently-turned farmyard manure. In this condition it rapidly flies off, and is wasted, unless measures be taken to prevent it. This is best done by sprinkling the manure with diluted oil of vitriol, or in stables by diluting it with water, and adding sawdust; exposing it in basins or other shallow vessels. The ammonia is thus converted into a salt, and is fixed.

In this fixed condition, or in the form of salts, ammonia is generally met with; for instance, the ammonia obtained from coal is usually converted into sulphate or muriate of ammonia. The ammonia contained in guano, soot, and other artificial manures, is chiefly present in the form of salt, in which state it cannot be recognized by its peculiar odour. It may, however, be detected by the following test:—Any salt of ammonia, as sulphate of ammonia from the gasworks, or the dry salt left after adding vinegar to hartshorn, in the above-named experiment, is mixed with a little slaked lime, and moistened with water. Free ammonia is now rapidly evolved, and may readily be recognized by its powerful smell. The acid in the salt of ammonia leaves the ammonia and combines with the lime: the ammonia is thus set free, and it resumes its volatile condition. Guano may be tested in this way for ammonia.

In this free and volatile condition ammonia exists in the air. How, then, it may be asked, is it conveyed to plants, for whose development it is indispensable? It is gathered from the air and supplied to plants by the following means:—

1. Plants possess the power of absorbing ammonia directly from the air by the leaves; but the quantity most plants obtain in this manner is extremely small.

2. The nitric acid, formed as before mentioned, during thunderstorms, and probably in smaller quantities at other times by the currents of electricity which constantly pass through the air, on meeting with the alkaline substance ammonia, combines with it and forms a salt,

called nitrate of ammonia: this salt is actually found in rain-water and snow, particularly in rain falling during thunderstorms. In this manner plants obtain a small quantity of ammonia.

3. In speaking of charcoal, its property of absorbing gases was noticed. It acts towards gases in a manner analogous to that of a sponge towards fluids. Charcoal in a porous dry condition eagerly absorbs ammonia, and retains it until moistened with water, when the ammonia it has absorbed is transferred to the water. On drying, the charcoal is again ready to absorb more ammonia. A substance closely analogous to charcoal is found in soils. It is called *humus*, and may be regarded as the charcoal produced from vegetable matter by decay, instead of by burning. This humus acts towards ammonia in the same manner as charcoal. In a dry state, it absorbs ammonia from the air, and collects it until the rain washes it out and conveys it to the roots of plants. On again drying, the humus collects a fresh store of ammonia. Other substances also present in the soil act in a similar manner; as clay, alumina, oxide of iron, &c. These materials will be described in the next chapter.

4. The soil always contains animal and vegetable substances, which by decay yield small quantities of ammonia. This is directly absorbed by the roots of plants.

The above are the means provided by Nature for supplying plants with ammonia, and are amply sufficient for the requirements of plants in a wild state, where the plants have plenty of soil to grow in. But with cultivated plants the case is different; these are often grown on poor, thin soils, that contain very little humus, and very little clay; the ammonia obtained from the air by these soils is insufficient for the proper development of the plants.

This deficiency is supplied by adding to the soil manures. Ammonia is an essential constituent of farmyard manure, guano, soot, and most other manures. By this means cultivated plants are supplied with the ammonia indispensable to their luxuriant growth.

From the ammonia supplied from any of the above sources plants obtain the materials requisite for the fabrication of their seeds, and other choice parts of the structure, that afterwards become the food of man and animals.

Since the action of ammonia, in the shape of manure, is a matter of great importance in Agricultural Chemistry, we shall again refer to this subject in a future chapter.

The atmosphere is admirably well adapted for the part it performs in the economy of nature.

In order that the exciting oxygen may not act too violently on the organs of animals, or combine too fiercely with combustible bodies, it is diluted with a bland indifferent gas—nitrogen. In this dilute condition, oxygen is restrained from injurious activity, at the same time it is at liberty to perform those functions allotted to it, for the proper maintenance of animal and vegetable life.

Again, carbonic acid is required. This, as we have seen, is a poison to animals, but a necessary food of plants. In order that plants may be supplied with this gas without its interfering with the health of animals, it is present in but a very small proportion, too small to act injuriously upon animals, yet large enough to supply all the wants of plants, the organism of which is so constructed that they are enabled to collect the small quantity of carbonic acid from a large bulk of air: this they do by the numerous leaves, which expose a very large breathing surface to the air.

The heavy carbonic acid gas and lighter oxygen and nitrogen gases are intermingled and maintained in a perfectly uniform state by a peculiar natural law, called the "law of diffusion of gases." This law may be described as a tendency all gases exhibit, when opportunity offers, to intermingle or diffuse themselves. Thus, a gas that possesses any peculiar smell, on being liberated in the air, does not remain in one spot, but rapidly diffuses and pervades the surrounding air, in virtue of this tendency. Again, a bottle or vessel filled with any one sort of gas cannot be retained in a pure or unmixed state

if the vessel containing it is not perfectly closed; if there is the least opening communicating between the bottle and the external air, the air will begin to pass in, and the gas begin to pour out; so that, after some little time, the gas will entirely escape from the bottle; and this operation takes place independently of the gas being heavier or lighter than the surrounding air. Were it not for this provision, the heavy carbonic acid gas would settle to the bottom of the atmosphere in the portion nearest the earth; but in consequence of this law, all the constituents of the atmosphere are equally distributed and preserved in a perfectly uniform condition. Portions of air have been collected from different parts of the earth's surface, and from different heights; in all cases, the composition is found to be the same, at least so far as the proportions of nitrogen and oxygen are concerned. In making this remark, we are aware that the air of certain localities is occasionally impregnated with certain vapours and miasma injurious to human life; but these local defects in the air, that are often produced by our own carelessness and neglect of sanitary matters, must not be considered as affecting in any way the general composition of the atmosphere. The air as we generally find it, or as it is provided for us by God, has no other effect on our systems than that of increasing our health, strength, and happiness.

Thus, in the atmosphere, we are able to perceive what we believe extends to all natural productions; viz., a perfect adaptation for the purposes they are provided to fulfil.

CHAPTER III.

THE SOIL.

Origin of Soils.

THE greater part of the surface of the land is covered by a layer of loose earthy matter, consisting of a mixture of stones of different sizes, sand, clay, and other mineral substances, with varying quantities of decaying vegetable and animal remains. This mixture is found to vary most widely in different localities, and constitutes what we call the soil. It is often but a thin layer, occurring in patches on the ragged surface of hard rocks, and capable of supporting nothing in the shape of vegetation but a scanty crop of mosses, lichens, and plants of this description. In other places, it consists of a deep mass of vegetable mould, so fertile and productive that the simplest cultivation is sufficient to raise from it the finest crops of grain, and every sort of food for man and animals. In many instances, deposits of this sort are so rich and of such apparently inexhaustible fertility, that year after year they produce the most abundant crops, without receiving anything in compensation in the shape of manure. Between these extremes in the qualities of soils, every description of soil is met with, differing as much in colour, texture, depth, and all other external characters, as in their capabilities of affording nourishment to plants.

It may be stated as a general rule, that all soils are produced from rocks by some or all of the numerous destructive operations to which rocks are exposed. This destruction, or breaking up of rocks, is effected by several

stupendous operations constantly going on in nature; for instance, volcanic action, floods, ice, and snow are described by geologists as active agents in changing the forms of rocks. The most effective agent, however, in altering the condition of rocks, and changing the character of the earth's surface, is the atmosphere, including the phenomena of rain, frost, &c., which act chiefly mechanically; as well as the chemical effects exerted by the oxygen gas, carbonic acid gas, and other constituents of the air already noticed.

Whenever the surfaces of rocks are exposed to the action of the weather, they undergo a slow but sure process of decay,—they rot, or disintegrate, as this process is termed by geologists. Fragments, more or less bulky, are constantly detached by frost, or some of the means before mentioned: these separate into smaller pieces, and finally crumble to powder. We have noticed, when speaking of the constituents of the air, the extraordinary avidity with which the oxygen gas unites with certain bodies that are in a condition to receive it. Bodies of this sort frequently occur in rocks and minerals; and supposing them to exist at the surface, or within the reach of oxygen gas, combination will ensue; and the resulting compound being always more bulky, or otherwise different from the original form, a disturbance of the surrounding parts takes place, accompanied by a loosening of the surface of the rock. Again, the carbonic acid of the air has a great tendency to unite with several mineral substances of constant occurrence in rocks. For instance, there is a mineral called felspar present in many rocks. Where this mineral is exposed to the carbonic acid of the air, it is slowly decomposed, and separates into two new substances, both of which are highly useful in contributing to the growth of plants. These two substances are called respectively potash and silica. We shall again have occasion to speak of these substances at greater length in another division of this chapter. We mention them here merely because the mineral felspar is a good illustration of a substance

belonging to rocks, that quickly become altered when exposed to the atmosphere. The mechanical effect of rain and frost must also be noticed in considering the various means that assist in the breaking up or crumbling of rocks and minerals. It is well known that frost is most active in this respect, at least in countries like our own, where intermittent frosts are common in winter. It owes this activity to the fact that water in the act of freezing expands with irresistible force; hence, if water is contained in any receptacle unable to yield to the increase of bulk, consequent on its freezing, the vessel is certainly broken: this is the case with the strongest iron vessels. In the fissures and interstices of rocks, water often accumulates, collected from the rain, dew, and other sources. This water will, on the occurrence of a frost strong enough to penetrate to these places, be frozen, and the brittle rock, unable to contain the water in its enlarged condition, is split and torn apart: on the ice thawing, or, in other words, the water again becoming fluid, these detached fragments are loosened, or fall away. By this means alone, enormous masses of rock are separated from the faces of cliffs, which in many places get visibly less and less every winter. The rain also materially assists the above-mentioned agents in their united attacks on the surfaces of rocks and minerals: it not only washes away the finer particles of detached material, and thus exposes fresh surfaces for the renewed action of oxygen gas and carbonic acid, &c., but in many instances dissolves the rock itself; and although the quantity of substance removed in this way is small, yet in the course of time appreciable diminution in bulk may be seen to have taken place from this cause.

From the above general facts we may form some notion of the manner in which the surface of an exposed rock, supposing it to be tolerably level, or at most undulating, may be gradually converted into a soil. We can easily imagine how by the unceasing action of the oxygen and carbonic acid of the air, combined with the occasional

effect of frost, rain, &c., fragments are loosened and detached; then crumble down and accumulate, until a layer of sufficient thickness is formed to retain enough water to preserve it in a porous, moist condition. Mosses and plants of a low organization will now spring up; then in time will decay, and furnish to the imperfect soil a quantity of decaying vegetable matter: it will now be in a condition to allow of the growth of a higher class of plants, whose seeds may accidentally be conveyed to the spot. Vegetation being once established, the vegetable matter—the humus we shall presently describe—will steadily increase, until a due proportion is present to constitute a soil. This soil will, of course, be strictly dependent on the characters of the rock from which it is formed; all its qualities—its colour, texture, &c.—will resemble those of its parent rock. If this rock contain all the mineral constituents requisite for the vigorous growth of plants, the soil will be a fertile one; if, on the contrary, the rock is deficient in any of these constituents, a soil of corresponding quality results. And this is the distinguishing character of soils of this class; viz., that they always partake of the qualities of the rock on which they lie, and consist for the most part of fragments of this rock in different stages of pulverization.

Another class of soils must now be noticed, whose origin is somewhat different from the above, and whose characteristic property is, that they do not always partake of the characters of the rock on which they rest. Thus far we have only spoken of soils that have been directly produced on the surface of rocks by the breaking up of these surfaces when exposed to the action of the weather. This operation can only take place when these surfaces are tolerably level, or at the utmost undulating, and never on the sides of rocks that are at all steep or precipitous. Before inquiring into the character of this second class of soils, let us briefly account for the occurrence, and describe the formation, of the vast masses of gravel, sand, clay, &c., which form so large a portion of

the surface of the land, and on which the greater number of soils rest.

Whenever the sides of rocks are steep and precipitous, or occur in the shape of cliffs, their destruction in the manner above described is considerably hastened; the fragments separated by any of the before-mentioned means fall away as soon as detached, and accumulate at the foot of the cliffs, or in the valleys of the mountainous district. The rain also washes away the finer particles, and carries them down to the lower grounds, when, perhaps, streams or rivers convey those substances still further away. Again, if districts like the above are exposed to floods, great quantities of loosened material are carried away, and transported to considerable distances; during which operation these rough fragments undergo more or less alteration in form, and assume the rounded shape commonly possessed by the pebbles found in gravel. While this loose matter is thus drifted along the valleys of the district in which it is formed, it will probably get mixed with the remains of other rocks of a different kind, brought down by similar means from neighbouring valleys; and thus will be deposited masses of material derived from several sources, in situations far away from the original position occupied by the particles of rock that composed them. These masses of drifted materials, altered by grinding against one another, by the action of water and other forces, make up the bulk of what we call clay, sand, gravel, &c.: they may all be described as mixtures of powdered rock, more or less altered by geological agents.

The surfaces of beds of this description are converted into soils by means similar to those we have already spoken of as acting upon rocks. The operation in these cases is, of course, quicker, and the resulting soil generally of a better kind than soils formed on the surface of hard rocks; since, in accumulations made up of fragments of several kinds of rocks, a greater number of the mineral constituents required by plants are likely to be present

than in any one rock. Other circumstances being equal, it may be assumed that a soil of this sort is superior to one of the former class.

Another matter connected with the formation of soils must now be briefly considered; viz., the occurrence of different kinds of soil in close proximity to one another. We often notice in districts of limited extent, several distinct kinds of soil, indicated by the colour, texture, appearance of the crops growing upon them, &c.; and if we are at all acquainted with these soils, we generally find them as different in quality as their appearance would lead us to suppose. A variety in the characters of the soil is often noticed in a comparatively small space of ground. More than one kind of soil is commonly found on a farm; even in one field it is not rare to find two or three kinds of soil.

This difference in the character of soils is, as we have seen, in a great measure dependent on the underlying rock, or the deposit on which the soil rests; hence we may generally assume that a difference in soil is accompanied by a corresponding difference in the subjacent rock or deposit; so that to account for the absence of uniformity in the soils of one district, we must seek for an explanation in the laws which regulate the position and arrangement of the rocks, beds of clay, gravel, and all other materials of the earth's crust.

Whatever kind of material may exist at the immediate surface of the earth, there is always found at a depth, varying in different localities, a solid rock. Of course the rocks found in this way vary to an immense extent in quality, character, appearance, and in every respect; but however different they may be, we are able to class them as belonging to one or the other of two great divisions into which all rocks are divided. In cliffs, quarries, railway-cuttings, and other situations where the interior of rocks is laid bare, and we have an opportunity of examining their structure, we may notice that most rocks are deposited in regular beds, layers, or slices, called by

geologists strata. In one and the same face of rock we may often see two or three different layers, composed of rocks widely different from each other in colour, texture, and every external quality. Rocks that are deposited in this manner, in layers or strata, are called stratified rocks. The number of stratified rocks is very great; but of their numbers, characters, qualities, or origin, we shall not speak, merely taking for granted their existence.

These stratified rocks are arranged in nature in a series one above another, in regular order. This series forms the upper or outer portion of the crust of our globe. In this series each bed of rock has its appointed place, and is generally found in this place,—at least in regard to the other rocks found above or below it.

It must also be mentioned that the accumulations spoken of by the names of beds of clay, sand, gravel, &c., have also been deposited in layers or beds, generally at the top of the stratified rocks. Hence we often find cavities and irregularities in the surfaces of rocks filled up and overlaid by materials of this sort.

At the bottom of this series of stratified rocks are found the unstratified rocks; that is to say, rocks that have not been deposited in this regular manner, but which are uniform throughout their bulk, from the lowest parts of them we can reach, to their highest summits. We say these rocks occur at the bottom of the stratified rock, but they also occur in all other positions with regard to the series of stratified rocks, protruding through them, displacing them, overlaying them, and rising far above them. Another name for these rocks, that will throw some light on the above statements, may now be noticed. They are also called volcanic or igneous rocks. These rocks are all the result of volcanic action. By the stupendous effects of volcanoes and other mighty agents, that at one time or another have extended to all parts of the earth's surface, these volcanic or unstratified rocks have taken up the extraordinary positions above mentioned, and in so doing have displaced the stratified rocks

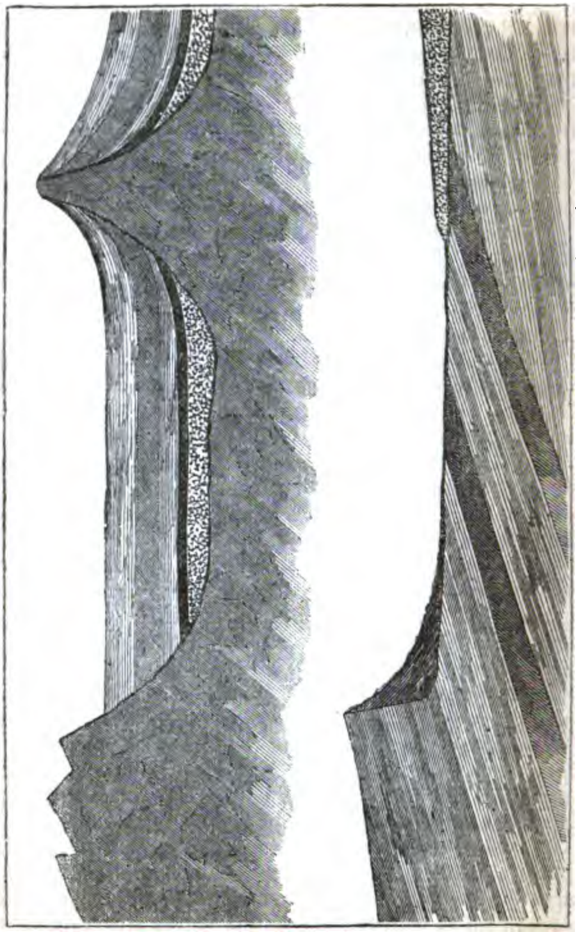
from their original level position, and compelled them to take up new positions at all sorts of angles with the level surface of the earth. Thus we find the series of stratified rocks, or parts of the series, inclined in all directions, often the edges of the beds uppermost. By this violent treatment, the layers of rocks have been somewhat deprived of their regular order, many of the beds having been removed in one place and heaped up in another, creating all sorts of apparent confusion.

To these effects of volcanic action must be added those of water, in the shape of floods, torrents, and inundations, which, by washing down and intermixing the materials of the rocks, have given rise to the deposits of sand and gravel, as before mentioned.

Notwithstanding this complete mixing up of rocks, the order of the stratified rocks is so far preserved, that the presence and position of any one rock or bed beneath the surface, may generally be inferred by the position of some other rocks that appear at the surface, or to which we have access. On this fact is based the application of geology to the purposes of mining, agriculture, well-sinking, &c.

Of course, it is difficult to form an adequate notion of the vastness of these operations, or of the stupendous means that must have acted to produce them. These beds often form entire tracts of country, and the edges of inclined strata are ranges of hills and mountains.

It is unnecessary for us to inquire into the causes that have led to this apparent confusion in the materials of the earth's crust. It is sufficient for our present purpose to know that such is the fact, and that in this manner is explained the occurrence of several kinds of rocks and deposits nearly together at the surface of the earth; and thus, also, to some extent, is explained how soils of a totally different character are found close together, and often alternating in the same field. The following sketch is intended to convey some notion of the structure of the earth's crust.



We may also remark that the above facts furnish us with an opportunity of seeing how much our welfare has been regarded by the Creator. This seeming want of order in the arrangement of the beds or layers in which the materials of the earth are deposited, is evidently kindly provided, in order that we may avail ourselves of the numerous treasures contained in some of these beds. Were it not for this apparent confusion, all but the layers exposed to the surface of the earth would be utterly inaccessible to us, and we should for ever remain in ignorance, and suffer from the want of the numerous useful things contained in the earth, which we at present enjoy.

We will now consider the soil more in detail, and first describe the various substances that are found in soils, their properties, uses, and their connection with agriculture.

Organic Portion of Soils.

The soils of our gardens and fields, widely differing in many respects, are so far alike as usually to present a brown or black colour, inclining more or less to red. This dark colour, found more especially in garden mould, and to a less extent in all cultivated soils, is due to a substance of vegetable origin, called *humus*.

In all soils are found vegetable remains in different stages of decay. Some of these so far retain their original form, as to be easily recognized as parts of roots, stems, leaves, and other parts of plants. There is also a black, friable substance, consisting of the above-named vegetable substances, more completely decayed, so that no organized shape can be perceived. This vegetable matter is called *humus*; and it is to this substance that the dark colour observed in soils is due.

Not long ago it was believed that the fertility of a soil is in direct proportion to the amount of humus it contains. Such, however, is not the case. It is now known that humus, though a most useful constituent of the soil, does not alone regulate fertility

That the fertility of a soil does not depend on the amount of humus it contains, is clear, when we recollect that peaty soils, naturally of inferior quality, contain more of this substance than any other description of soils. Again, many soils famous for the heavy crops of wheat, and other crops they produce, contain but a small proportion of this substance.

Humus, as we have said, is the dark-coloured substance resulting from the partial decay of vegetable matter, and is always formed when organic matter of this description decays in damp situations; as when the stumps of trees are suffered to rot in the ground, or when leaves decay in heaps. In a separate state, humus is a dark-coloured, friable, porous, light substance, or rather mixture of substances, since the humus generally contains several bodies, known to chemists by the names of humic acid, ulmic acid, ulmine, &c.; but as these compounds resemble each other very closely, and as their action in the soil seems to be much the same, we think it advisable to speak of them all under the general term of *humus*. We may regard this substance, or mixture of substances, as a kind of charcoal, since it possesses many properties in common with this body, particularly that of absorbing and retaining gases: it is on this property of humus that its value in the soil chiefly depends. We have already remarked, that one of the sources from which plants derive the ammonia required for their growth is the atmosphere, where this valuable substance exists in a gaseous form in minute quantity; and that this ammonia is absorbed by the soil, and supplied to the roots of plants. Humus helps to perform this office in the soil. In a dry state, it collects ammonia from the air; the rain washes out the ammonia, and presents it in a dilute state to the roots of the plants.

Humus is also useful in the soil as a source of carbonic acid gas, another of the materials already described as necessary for the growth of plants. By slowly decaying, humus

furnishes a constant supply of this substance to the roots of plants.

Thus we see humus plays an important part in supplying food to plants. It is, however, occasionally found in a condition different to that we have just described; and, so far from performing the two important functions we have mentioned, it refuses to decay, and seems to be an incumbrance to vegetation. In this form it exists in boggy and peaty soils, and is popularly, though erroneously, called "sour humus." From this torpid inactive state humus may generally be aroused by the use of lime, as we shall notice on a future occasion.

Besides humus, other substances of vegetable and animal origin are also present in the soil; as the undecayed stems, roots, and other parts of plants, and the larvæ of insects: these materials are all comprised in the term "organic matter," applied to them by chemists.

If a portion of dry soil is burned in an iron spoon, or other more convenient receptacle, over a lamp or fire, the soil first blackens, sometimes smokes, gives off the peculiar smell of burning earth, and generally assumes finally a red colour. These changes are principally due to the destruction by fire of the organic matter present in the soil; the distinguishing property of all organic compounds being that they are destroyed, or separated into their constituents by burning. The greater portion of the soil remains behind, and is generally a little darker coloured or redder than before burning, but otherwise unchanged by the action of heat. This is the

Mineral or Inorganic Portion of the Soil.

This portion of the soil forms in most cases by far the greater portion of its bulk and weight. It consists of a mixture of mineral substances, all of which take a more or less active part in assisting the growth of vegetables. While some of them act only mechanically by giving bulk and porosity to the soil, the greater number, in addition

to this effect, act also chemically, that is to say, directly contribute to the growth of plants by supplying them with indispensable materials. The number of mineral constituents usually found in soils is eleven or twelve, and what may at first seem astonishing is the fact that this number seldom varies in fertile and unfertile soils. In soils of almost every kind this number of materials is present. The presence or absence of certain materials determines in a great measure the quality of the soil. The fertility of land, however, is likewise affected by the condition in which these materials occur; for instance, the compound called phosphoric acid, before referred to as a substance intimately connected with the fertility of soils, is very seldom absent in any soil; but although a soil may contain considerable quantities of phosphoric acid, the direct supply of this fertilizing agent is often marked with beneficial results. Paradoxical as the fact may seem, it is easily explained, as follows:— The phosphoric acid naturally present in the soil may exist in one of its stony, insoluble shapes before alluded to; in this form it is incapable of entering into the delicate vessels of the roots of plants, and remains ineffective, whilst the supply of the same substance in a condition in which it can be taken up by plants produces most beneficial results. Hence also the necessity of employing proper means of rendering available the useful materials already present in a soil.

The names of the inorganic or mineral substances belonging to the soil are—Silica, Alumina, Lime, Oxide of Iron, Magnesia, Potash, Soda, Sulphur, Phosphorus, Chlorine, Fluorine. In this list we have arranged these materials in the order of their abundance, as they occur in a soil of average fertility. We will now proceed to describe the more prominent characters of each of these substances.

Silica is the predominating constituent of most soils, rocks, and minerals; it forms a large proportion of clay, and the chief part of sand; in short, silica is the most

abundant solid material of the earth. In a pure state, silica is a white gritty powder, which is scarcely affected by any ordinary chemical agent, and remains unaltered when exposed to the strongest fires. It consists of silicum or silicon, and oxygen. These negative properties extend to nearly all the ordinary compounds of silica; there is, however, one remarkable exception in the case of soluble silica, as it is called—a modification of silica that is soluble in water. This compound is found in all fertile soils, and performs an important part in relation to the growth of plants. A great many plants contain silica as an essential part of their substance. In wheat, barley, and plants of this description, we find a considerable quantity of silica, which has been conveyed into their structure as soluble silica by the agency of water. We are familiar with several combinations of silica in the different varieties of glass commonly met with. Bottle-glass, window-glass, &c., are all composed of silica, with smaller quantities of other materials. Silica is also called silicic acid, and occasionally silex.

Alumina.—Alumina combined with silica forms pure clay. The white clay of which pipes are made is nearly pure clay. The clays found in soils have usually a red colour, due to the oxide of iron they contain. They consist of pure clay intimately mixed with fine sand, oxide of iron, and some other substances. Pure clay in a moist state is a smooth, plastic material, retains water with great obstinacy, and on drying retains the shape given to it when moist. Alumina in a dry state much resembles silica: it is a white, gritty, solid, exceedingly hard substance, which is sometimes found in nature in a crystallized state. The gems ruby and sapphire consist of crystallized alumina. Alumina consists of oxygen gas and the metal aluminium. It will be recollected this is the metal that has recently attracted so much curiosity under the name of the new metal made from clay. It is, however, a mistake to suppose that this metal has been newly discovered. This is not the case: it has been

known for some years, but only to chemists. Like the metal calcium, contained in lime, or sodium in soda, aluminium could only be procured in small quantities. The only thing new about this metal is the discovery of a more ready method of separating it from its combinations, and obtaining it in larger quantities, so as to admit of its qualities being better observed. By means of an improved process, aluminium is now obtained in bars and plates, and is made into small vessels. It is a metal whose appearance is intermediate between that of silver and zinc, its most remarkable quality being its extreme lightness. A bar of the metal lifted up conveys the impression of lifting only a rod of wood. It would no doubt be used for domestic purposes, if a more economical method of preparing it were known.

Persons unaccustomed to remark chemical phenomena may well be astonished on being told that a bright silvery metal is contained in the clay of our fields; yet such is the case: in every 2½ lb. of pure clay there is 1 lb. of aluminium.

And now, while speaking of aluminium and the other metals of the soil, let us make a few additional remarks on the substance with which they are nearly all found combined. This substance is oxygen gas, the same gas we have described as the principal constituent of the atmosphere. Is it not extraordinary that this element, displaying so many active properties when in the state of gas in atmosphere, should also exist in a solid form in earth and minerals under a totally different aspect, as remarkable for its passive and inactive qualities, as it is for the reverse of these qualities when it occurs in the air? Oxygen furnishes us with a good example of a body that assumes more than one condition, and also of the fact that one substance may present several different shapes when combined with different bodies. Thus we have already seen it forms the greater part of silica or sand, also of alumina and clay; and we shall find it forming the chief portion of all the materials of

the soil. To return to our subject, let us inquire into the connection of alumina with agriculture.

Alumina does not directly contribute to the growth of plants,—it is seldom absorbed by their roots, and therefore is no direct food of plants. In the form of clay, however, it is a most essential constituent of the soil.

Clay, as above noticed, is very retentive of water; hence, in hot, dry weather the clay of a soil becomes of great service in protecting the plants grown upon it from the injurious effects of drought. At times, when the surface of the soil is apparently parched for want of water, if a little of the upper dry earth is removed, the subjacent soil will generally be found moist enough to prevent the plants growing in it from suffering for want of water. This property of soils is chiefly due to the clay and other combinations of alumina they contain.

Another important use of clay in soils depends on its power of sucking up and retaining the easily soluble salts supplied in manure and from other sources. Were it not for this property of clay, these fertilizing substances would be washed down by the first heavy rain into the subsoil, and be taken out of the reach of the roots of plants. By this provision, however, they are retained in the clay, and supplied to the plants as required. This property of clay enables us to understand the expression often applied by farmers to soils deficient in clay; such as sandy and light soils, which are said to be "hungry." Another important property of clay is its power of absorbing the valuable ammonia from the atmosphere, and conveying it to the roots of plants.

Oxide of Iron.—This substance is closely connected with the two preceding ones, being generally found with them in greater or less abundance in clays, sands, and other minerals. It is oxide of iron that gives rise to the prevailing red and brown tints of these substances. The blue colour sometimes noticed in rocks and clays is also due to oxide of iron of another sort. Blue clays on

exposure to the weather rapidly change their colour, and finally become red. This circumstance is explained by protoxide of iron, to which the blue colour is due, rapidly attracting oxygen from the air, whereby it is converted into the red or peroxide of iron.

When a piece of bright iron is exposed to damp air, it quickly becomes covered with rust, and if exposed long enough, is entirely changed into rust. The red-coloured friable substance formed in this way is oxide of iron, or the same substance which is found so abundantly in soils, sands, rocks, &c. In a moist state, as it is found in the clay of soils, oxide of iron, like alumina, possesses the power of absorbing ammonia from the air.

The other oxide of iron, above referred to under the name of protoxide, has usually a blue tint, and occurs in the well-known salt of the shops called green vitriol or copperas. This substance is occasionally found in soils, and always exerts an injurious effect on vegetation. It is occasionally formed in soils from a mineral of not unfrequent occurrence, called iron pyrites, or iron combined with sulphur. This substance may often be seen forming yellow metallic scales in the cracks of lumps of coal. When iron pyrites is exposed to the weather under certain conditions, it is converted into sulphate of iron, or green vitriol, which, if present in more than a very small quantity, impairs the fertility of the soil. The barrenness of certain spots of ground has often been traced to the presence of sulphate of iron in injurious quantities: it occurs also occasionally in boggy and undrained land. By prolonged exposure to the air and weather, sulphate of iron loses its injurious properties by being changed into the red or harmless oxide of iron: hence, the obvious remedy for land injured by the presence of this substance is thorough working, and fallowing. The same end may be more effectually attained by a liberal addition of lime to the land.

Iron in the shape of oxide of iron is very widely spread · the earth's surface, being present in small quantities

in nearly all rocks and soils, and is occasionally found in them in so large a proportion as to admit of their being profitably employed as sources of metallic iron.

Lime.—Lime, in the chemical sense of the term, means the hot caustic substance recently removed from the lime-kiln, where it has been prepared by means of fire from limestone rocks, which for the most part consist of carbonate of lime; that is, lime combined with carbonic acid—the gas, it will be remembered, which forms a small proportion of the atmosphere. On burning these rocks, the carbonic acid contained in them flies off into the air, and lime, in the proper sense of the word, mixed with any foreign matter the rock may contain, remains in the kiln. In this state it is commonly called quick-lime, caustic lime, or hot lime: it consists of oxygen gas, combined with the metal called calcium. In this freshly-burned state, lime is strongly caustic or alkaline; that is to say, it possesses a peculiar acrid taste; and when moistened, produces a soapy sensation on the fingers. This effect is due to its corrosive action of destroying animal and vegetable matter. For this reason it furnishes us with a valuable means of improving land suffering from an excessive quantity of vegetable matter, as in peaty and boggy soils. On this, with other equally important properties, is based the use of lime as a means of improving defective soils; and since this operation of liming is an important one in Agricultural Chemistry, we shall speak of it at greater length in a future chapter, amongst other allied operations.

When a lump of quicklime is sprinkled with water, it steams, cracks, gives off much heat, swells up, and finally falls to an exceedingly fine, white, *dry* powder: all the water used in the operation disappears. The lime is now said to be slaked, and retains its former caustic qualities. The proper name of this slaked lime is hydrate of lime: the water used in slaking has entered into chemical combination with the lime, and with it has formed a new substance, in which none of the ordinary properties of

water can be recognized. The heat given off during the process of slaking is the result of the violent chemical action. Without entering into the laws that regulate the production of heat, we may state, as a general fact, that a liberation of heat, or, more strictly, a disturbance of temperature, accompanies every chemical action.

The slaking of lime is caused by the great attraction possessed by lime for water; or, as chemists say, the affinity of lime for water is strong. The above changes are represented as following the rapid slaking of lime by pouring water upon it. It must be understood that the same thing takes place whenever the quicklime meets with water, as when exposed to the air and allowed to slake spontaneously. In so doing, it derives the requisite amount of water from the atmosphere, which, as we have seen, always contains considerable quantities of watery vapours.

Besides the affinity for water, lime has a great attraction for carbonic acid gas. Slaked lime exposed to the air, especially when moist, rapidly absorbs carbonic acid (hence the use of lime in removing carbonic acid from places where it has accumulated to an injurious extent), and is converted into carbonate of lime; in fact, it returns to its original condition, and, chemically speaking, is in the same state as it was before burning; but its physical form is very different: it is now in a fine state of division.

We avail ourselves of this property of lime when applying it to land. As it would be next to useless to add to a soil carbonate of lime in the shape of lumps of limestone rock, we should secure the fullest benefit by adding and perfectly distributing the same material, prepared from caustic lime in the manner just described, simply because in this finely-divided state it can be intimately mixed with the soil and at once come in contact with the substances on which it is intended to act. We may remark by the way, that the importance of attending to the state of division of a material intended

to be added to the land, extends to manures of all descriptions.

Lime is indispensable to the growth of plants: in many plants it is an abundant constituent of their ash, or mineral portion, and is found in greater or less quantity in almost all plants. Thus we see lime is a very important material of soils. No soil—or rather, no cultivated soil—is absolutely destitute of lime, although the proportion of it in many soils is often less than is required for a healthy growth of plants; and consequently the addition of lime in these cases is calculated to lead to an increase of produce. In the shape of carbonate of lime, by far the greater part of the enormous quantity of lime occurring in the earth's crust is found.

Lime also occurs, but less abundantly, in other states of combination; for instance, as sulphate of lime, phosphate of lime, silicate of lime, nitrate of lime, &c. Two of these we must briefly describe. Sulphate of lime is also called gypsum, and is better known by its common name of plaster of Paris. It is found in tolerable quantity in many localities, often beautifully crystallized, and is widely distributed in most soils, but in very small quantity. It is found in the ash of many plants, especially clover, beans, &c.

Sulphate of lime, as its name would imply, consists of lime combined with sulphuric acid, or oil of vitriol, and generally contains a definite quantity of water chemically combined with it. On burning, this water is driven out, and the resulting burned sulphate of lime is plaster of Paris.

Since sulphate of lime is seldom present in soils in quantities sufficient to supply the demands of cultivated crops, gypsum is a useful manure, since, in addition to its direct action of supplying gypsum to plants that require it, a second and more important office is performed by gypsum in the soil; namely, that of converting the volatile combinations of ammonia into more permanent forms. This important property of gypsum will be spoken of under the article "Manures."

Phosphate of lime seldom occurs naturally in soils: it exists in certain rocks, and occasionally entire beds of it are found. The minerals called apatite, phosphorite, &c., consist chiefly of phosphate of lime: hence these minerals are valuable sources of phosphate of lime, for the preparation of superphosphates and manures of this description. As this compound of lime will also be considered amongst the manures, nothing further need be said of it in this place.

Magnesia.—This substance resembles lime in many of its properties, and is generally found accompanying lime in rocks and minerals. Several kinds of rocks contain a large proportion of magnesia; as dolomite, magnesian limestones, serpentine, &c. Magnesia, like lime, mostly occurs as carbonate, or combined with carbonic acid. It is also common as silicate, or combined with silicic acid. A variety of this combination of magnesia is well known as meerschaum, the material of pipe bowls. Two other forms of magnesia are familiar to most of us, viz., the magnesia of the shops, which is carbonate of magnesia artificially prepared, and Epsom salts, consisting of magnesia combined with oil of vitriol, or sulphuric acid.

Magnesia is present in all cultivated soils, and is very necessary to the healthy growth of many plants. In wheat, barley, and plants of this kind, magnesia is always found, combined with phosphoric acid, especially in the shells or bran of the grain. Its presence in the soil seems to be necessary to the proper development of the seeds of these plants. Phosphate of magnesia is found in company with phosphate of lime in the bones of animals.

Potash.—When wood is burned, a greyish-white ash is left: this ash consists for the most part of potash, or more correctly, carbonate of potash.

The ash left on burning wood and other parts of plants in all cases consists of the mineral substances taken up by the plant during its growth. The presence of this mineral matter in plants is not accidental; it is the mineral food of the plant, and as necessary to its growth

as the other kinds of food we have before noticed; as ammonia, carbonic acid, &c. This subject being a very important one in Agricultural Chemistry, will be considered in a future chapter, and therefore need not be entered upon in this place. We allude to it because the potash in most cases forms a large proportion of the mineral constituents of plants and trees, and consequently is found in greatest abundance in their ash. For this reason potash is a most essential material in all cultivated soils. The principal source of potash is the mineral felspar. This mineral, as we have before noticed, occurs in many rocks; and hence is found in soils. From this mineral potash is slowly liberated by the action of the carbonic acid of the air, which renders it available for plants, by whose roots it is absorbed.

On burning the vegetable portion of wood, the potash, amongst other mineral substances contained in it, is left behind in the shape of carbonate of potash. From this source nearly all the various compounds of the potash of commerce are obtained. In countries where wood is of little value, as in Canada, Russia, and other places, it is burned in immense quantities for the sake of the ash. This ash, by a simple process, is converted into the potashes of the shops. The same material partly purified is the pearl-ash: both substances consist of impure carbonate of potash.

In some parts of this country the wood ashes are collected and extracted with water. This extract is technically called "lye," and is used to "soften" the water used in washing linen. It owes its virtue to the carbonate of potash it contains. The carbonate of potash in this lye, and from other sources, has a peculiar caustic taste and soapy feel; it is "alkaline," like the liquid ammonia and lime before described. Substances possessed of this quality are called alkalies: hence potash is an alkali. When a solution of carbonate of potash, or what is the same thing, the lye above noticed, is boiled with caustic lime, and the mixture allowed to stand until the upper

portion is clear, a solution of caustic potash is obtained. This solution, when strong, is a very corrosive liquid, capable of dissolving skin, hair, and all animal matters. The soapy feeling experienced on the fingers when handling alkaline substances, as potash, soda, and in a less degree soap, is due to a thin surface of skin being dissolved and removed by these alkalies. Caustic potash in a dry state consists of the metal potassium and oxygen gas. Potassium is a bright silvery metal, so light that it swims upon water, and in so doing takes fire. One of the prettiest chemical experiments consists in displaying this property of potassium.

Potassium is a most interesting substance apart from its connection with agriculture, inasmuch as it was the first of the light metals discovered at the beginning of the present century by the distinguished chemist Sir Humphrey Davy. Before this period, no one conceived that a bright metal was concealed in potash or in soda. These substances are now called oxides of their respective metals—combinations of oxygen gas with potassium and sodium—and are considered strictly analogous to the rust or oxide of iron, which contains the metal iron and oxygen gas.

The use of wood ashes as a manure will be spoken of amongst the other manures in a future chapter.

Soda very much resembles potash. While potash is an abundant mineral substance of land plants, soda occupies the same position with regard to marine plants or seaweeds. These plants contain large quantities of soda: it seems to perform in them functions analogous to those performed by potash in land plants.

On burning seaweeds, carbonate of soda is obtained; a salt closely analogous to carbonate of potash. This operation is carried on at different parts of our coasts, where seaweeds are collected and burned. The resulting ash is called "kelp:" it is largely consumed by the manufacturers of iodine, and also used in soap-making, glass-making, and other trades. Kelp was until comparatively lately

the only source from which carbonate of soda, or washing soda, and other salts of soda, were obtained. At the present time carbonate of soda is obtained from common salt. The proper name of common salt is chloride of sodium, a familiar substance that furnishes us with a fine example of chemical transformation. Common salt consists of the metal sodium (a metal analogous to potassium) combined with a most poisonous gas called chlorine. Every 58 lb. of common salt contain about 35 lb. of this gas, which in a separate state possesses the following formidable characters:—it is a heavy green-coloured gas, possessing, when mixed with the air, a peculiar suffocating smell; in an unmixed state it must not be inhaled, since it acts when breathed as a violent poison; indeed, this substance is always carefully handled by the chemist, and always prepared with much precaution. Yet this gas, of such ferocious qualities when uncombined, by union with sodium and other metals, becomes perfectly tame and passive, loses all its poisonous properties, and in the case of common salt becomes a most useful and beneficial addition to our food. Such is one of the many extraordinary facts presented to us on all sides by Chemistry.

It is in the shape of common salt that soda chiefly occurs in soils, and generally but in small quantity. Common salt is often extolled as a valuable general manure; but however useful it may be for mangolds and a few other crops, or for destroying insects, its value as a general manure is very doubtful, at least in this country. On certain parts of the continent the use of salt is attended with decided improvement in the land; but in this country instances of this sort are rare. This may be explained by the fact that most of our soils naturally contain enough salt for supplying the small quantity required by plants. The occurrence of salt in soils, often found on rocks entirely destitute of salt, is accounted for in the following manner. The rain is occasionally found to contain appreciable quantities of salt, derived from the

sea; the spray and invisible particles of sea-water are often carried by high winds to great distances inland, where it is slowly deposited. The results of careful experiments, made with the view of determining the amount of salt conveyed to the land in this manner, distinctly show that the salt found in our soils is mainly derived from this source.

Phosphorus.—All the materials we have described hitherto as belonging to, and forming part of, the soil, are combinations of metals with oxygen gas:—hence their proper name, metallic oxides. Two or three other substances of another type must now be noticed, which resemble the metallic oxides in so far that they are also combinations of oxygen, and are consequently oxides, but differ from them in possessing, when in a separate or free state, properties altogether different and antagonistic to those we have hitherto considered. These, it will be remembered, always possess, when soluble in water, a peculiar caustic taste called "alkaline:" hence they are called by chemists alkalies, and also bases. This latter term is applied to all compounds of the same character, whether alkaline or not. Two or three members of another group of compounds must now be noticed, whose oxides possess qualities the reverse of those belonging to bases or alkalies. They are sour compounds, and called by chemists acids. Alkalies and acids are great antagonists, because, whenever they meet they fight, so to speak, and deprive each other of their distinguishing properties;—they neutralize each other, and produce a new class of bodies called salts. We thought it proper to describe thus briefly the formation of a salt, to account for the circumstance that few acids or bases are ever found in a free state in nature: they all occur in the form of salts. Moreover, nearly all the constituents of soils exist in the shape of salts.

Phosphorus when combined with oxygen forms phosphoric acid. Phosphate of lime, phosphate of soda, &c., are all salts of phosphoric acid.

In the state of salts, phosphorus is contained in nearly all soils, but often in very minute quantities.

In the shape of phosphate of lime, phosphorus occurs in apatite, phosphorite, and the other minerals alluded to in a former chapter. The roots of plants take up phosphoric acid from the soil, and convey it to the different parts of their structure. Phosphorus is always found in the choicer parts of plants, as the grain of wheat, barley, &c.; in the bulbs of turnips, mangolds, &c.; in fact, in all vegetable productions used as food for man and animals; and is always found in largest quantity in those portions of the plant remarkable for their nourishing properties. We shall see presently that phosphorus, like nitrogen, is intimately connected with the nutritive value of feeding materials.

From the combinations of phosphorus, present in small quantities in their food, animals obtain the phosphoric acid essential to the development of their bones. The bones of animals contain a large proportion of phosphorus in the shape of phosphate of lime. Bones are the source from which the greater part of the phosphorus and compounds of phosphorus of commerce are obtained.

When bones are burned, they first blacken, and shrink in bulk; by longer burning, they are converted into a white ash. This ash is the mineral part of the bone: it consists chiefly of phosphate of lime. By suitable chemical means, the phosphoric acid can be separated from the lime, and from phosphoric acid phosphorus may be prepared. In a separate state, phosphorus is a yellowish semi-transparent solid, soft like wax, and possessed of a peculiar garlic-like smell. It is remarkable for being the most inflammable substance known, the least violence or friction being sufficient to set it on fire. On burning, it gives giving off clouds of white smoke. This smoke is phosphoric acid.

The fact that a large amount of phosphorus is required by all crops, and that it is naturally present in the soil

only in small quantity, readily explains the reason why the artificial addition of this substance is generally followed by an increase of produce. Phosphorus is conveyed to the soil by employing phosphatic manures, such as bone-dust, superphosphate of lime, &c.

Sulphur.—The proper name of the substance commonly known as brimstone is sulphur. Combined with other bodies, sulphur is invariably present in the soils of our fields. Thence it is collected by the roots of plants, in whose organism it performs important functions, and, like phosphorus, is necessary to the development of those portions of plants which afterwards become the food of man and animals. Sulphur is found in large quantities, mixed with earthy impurities, in the neighbourhood of volcanoes, and by a simple process is purified and prepared in the form usually imported into this country. It is also found in considerable quantities in the mineral iron pyrites.

When sulphur is burned, it combines with the oxygen of the air, and forms sulphurous acid, the unpleasant-smelling gas generated on lighting lucifer matches. This sulphurous acid, by suitable means, can be converted into sulphuric acid, or oil of vitriol. This compound is prepared on a large scale in manufactories, where several thousand gallons are annually produced.

Sulphur is an important article of commerce to this country, since, in the shape of oil of vitriol, it is indispensable in the carrying on of numerous trades and manufactures, and in an indirect manner is intimately connected with the processes of agriculture. Superphosphate of lime, a manure which may be regarded as a necessity in the present system of cultivation, is prepared by the direct agency of sulphuric acid.

Enormous quantities of sulphuric acid are annually consumed in this manufacture alone.

Chlorine and Fluorine.—Very little need be said of either of these substances, since chlorine has been before mentioned, and the latter substance—fluorine—is not of

much interest in Agricultural Chemistry. Chlorine is chiefly met with in the form of common salt. In this form it exists in enormous quantities in the water of the sea, but is only sparingly distributed in the soil. In a separate state, chlorine seems to take no part in the economy of nature.

Fluorine is very much like chlorine, and occurs in minute quantity in soils, combined with lime. It also exists as a mineral called fluor spar. It is taken up by plants, and conveyed to the bodies of animals, where its chief use seems to be in forming the enamel of teeth, and in smaller quantities is present in their bones.

Classification of Soils.

Of the substances above enumerated, by far the more abundant in all soils, are the four or five first in the list, viz. silica, alumina, lime, and organic matter; next in quantity, are oxide of iron, magnesia; then potash and soda; finally, in very small quantities, phosphoric acid, sulphuric acid, and chlorine. These statements apply to all sorts of soils: whether a soil be light or heavy, calcareous or sandy, fertile or barren, its bulk is always made up by some of the six materials first named; the others always form but a small proportion of the soil, amounting together seldom to more than a hundredth part of its weight.

All the constituents described above, may be grouped into four divisions, and considered as belonging to, and forming part of, one or more of the four natural materials, which, arranged in different proportions and distributed through various quantities of undecomposed fragments of rock or stones, make up the bulk of all soils. These four compounds are familiarly known to us as sand, clay, lime, and organic or vegetable matter. An idea of the general composition of each of these four mechanical constituents, as they are sometimes called, may be gathered from the following table :—

Sand may contain—

Silica,

In small quantity, { Oxide of Iron, Lime.

Clay may contain,—

Silica,

Alumina,

In smaller quantity, { Lime, Potash, Soda, Phosphoric Acid, Sulphuric Acid.

Limestone or Calcareous Matter may contain—

Lime,

In small quantity, { Silica, Alumina, Oxide of Iron, Potash, Soda, Phosphoric Acid, Sulphuric Acid.

Organic Matter, or Decaying Vegetable and Animal Matter, may contain—

Humus,

Other Vegetable Remains,

Animal Remains,

In small quantity, but in a fine state of division, and well incorporated (the mineral constituents of former generations of vegetables or crops), { Silica, Potash, Soda, Phosphoric Acid, Sulphuric Acid, Chlorine.

According to the preponderance of one or more of these compounds, soils are arranged in the following classes :—Vegetable moulds, clay soils, sandy soils, calcareous soils, marly soils, and loamy soils.

Let us now briefly consider the leading characters of each of these classes of soils.

Vegetable Moulds.—All soils that contain a large quantity of vegetable matter, either in the shape of humus or otherwise, are included in this class. Here we find two distinct varieties of soils; viz. fertile moulds and peaty or boggy soils. By a large quantity of vegetable matter is meant more than 5 or 6 per cent.,* which is the quantity usually found in ordinary soils. In garden moulds there is generally about 9 to 10 per

* In stating the quality of soils, we generally speak of their composition in one-hundred parts, or say so much per cent. of a substance.

cent. of organic matter; in peaty and boggy soils, often as much as 70 per cent. Hence we see the amount of organic matter is no criterion of fertility. The superior quality of garden mould, as compared with the soils of our fields, is due not so much to the organic matter or humus it contains, as to its finely-divided and well-worked condition, and the more complete mixture of its constituents.

In boggy and peaty lands it is this excess of vegetable matter that renders them unproductive. Hence the proper course towards their improvement consists in employing the most efficient means at our disposal for getting rid of or altering the condition of this vegetable matter: in most cases, burning, and the liberal use of lime, will effect this object.

Clay Soils.—Soils of this description are distinguished by their cold, dense qualities, and are well known as "heavy soils," for the reason that the successful cultivation of these soils can only be accomplished by the expenditure of a great amount of labour, strength, and capital. We have already noticed, while speaking of alumina, the peculiar retentive quality of clay, and have remarked upon the usefulness of this property of clay. But in soils that consist almost entirely of clay, this quality becomes too much of a good thing, and constitutes the chief obstacle that the tiller of clay soils has to encounter. For this reason, little can be done with clay soils until they are thoroughly drained.

Another operation, often found very successful in the reclamation of unproductive clay land, is burning; liming also is a valuable means of bringing into cultivation soils in which an excessive quantity of clay is the cause of infertility. The subsequent treatment in the management of clay soils consists in working them in as complete a manner and as often as the state of the ground will permit.

With a great amount of labour and expense clay soils

become exceedingly fertile, and return a good profit to the cultivator, since they require less in the shape of manure than most other kinds of soil. This is because many clays contain inexhaustible quantities of the mineral substances required by plants, and only require proper management to yield those materials in an available form. Hence clay soils are particularly adapted for the production of grain crops, especially wheat.

Sandy soils are those that contain from 70 to 90 per cent. of sand. They are distinguished by characters the reverse of those possessed by clay soils. They are light, porous, deficient in retaining moisture, they soon suffer from drought, and by heavy rains are deprived of the little valuable matter they may originally contain. The chief defect of these soils is this want of retentiveness, which allows the rain and water to wash out the valuable portions of any manure that may have been supplied, before the roots of the plants have had time to take up these substances. Hence the term "hungry," applied by farmers to this sort of soil. For this reason, if at all practicable, the manure should be added in small and frequent doses. It is for the same reason that the system of liquid manuring succeeds on soils of this description.

The improvement of such soils obviously consists in adding clay, marl, &c., if such materials can be procured at a price at all consistent with the benefit they are likely to produce.

Calcareous, or Lime Soils.—This is a most extensive class of soils, including soils of most diversified characters. To this class belong all soils in which carbonate of lime forms the greater part of the bulk, or that contain more than 20 per cent. of lime; but since the rocks from which these soils are formed vary most widely in their composition and physical characters, it follows that soils of every degree of fertility are included in this division. Lime soils are

generally light soils, and easy to work; the greater number are poor thin soils; some of them, however, as those resting on the lower chalk formation, are exceedingly good soils, and remarkable for their fertility.

Lime soils of all descriptions are particularly adapted for the growth of leguminous crops, as clover, pease, sainfoin, &c. This latter plant is particularly fitted for thin soils resting on limestone rocks, since it has the power of sending its roots to great distances in the fissures of the rock, and extracting and bringing to the surface the fertilizing materials that the rock may contain.

Marly soils are those that consist of a mixture of clay and lime, and contain from 5 to 20 per cent. of lime, and whose qualities are of course intermediate between clay and calcareous soils. These soils are subdivided into clay marls, chalk marls, sandy marls, &c. Marls of different kinds are often used as manures, and generally with good results. The effects produced by marls are usually more striking than those which follow the application of other calcareous matters. This superiority is mostly due to the phosphoric acid which many marls contain.

Loamy soils are intimate mixtures of sand, clay, lime, and organic matter. They are subdivided into clay loam, sandy loam, &c. These are probably the richest sorts of soils, next to the better sorts of vegetable moulds. Like vegetable moulds, they contain a fair proportion of clay, sand, lime, &c., and the whole in a friable well-mixed condition; and it is to this fact that the superior quality of loamy soils is mainly due.

In order to convey a better idea of the composition of soils, we annex the following table, which includes analyses of each class.

COMPOSITION OF SOILS.

	A Fertile Vegetable Mould.	A Good Sandy Soil.	A Fertile Clay Soil.	A Fertile Loamy Soil.	A Calcareous or Lime Soil.	A Marly Soil.
Organic Matter, Humus, &c. ..	10·08	·49	3·38	11·24	6·33	10·50
Oxide of Iron	6·30	3·19	8·82	4·87	9·31	11·92
Alumina	9·30	2·65	6·67	14·04		
Lime	1·01	·24	1·44	·83	Car. of Lime 54·56	19.92
Magnesia	·20	·70	·92	1·02	trace	·25
Potash	·01	·12	1·48	2·80	1·03	·71
Soda		·02	1·08	1·43		
Phosphoric Acid	·13	·07	1·51	·24	trace	·38
Sulphuric Acid	·17	trace	trace	·09	trace	·04
Chlorine		trace	—	·25	—	·76
Insoluble Silicates (clay and sand)	72·80	92·52 (sand)	72·83	63·19	28·77	55·52
Carbonic Acid and loss	—	—	1·87	—	—	—
	100·00	100·00	100·00	100·00	100·00	100·00

This classification is usually adopted in the description of cultivated soils. The general composition of a soil, and its connection with one or other of the above classes, may in some measure be judged by examining it in the ordinary manner, by its colour, texture, the characters of the stones it may contain, the quantity of organic matter, &c. But to be able to speak positively on this subject, it is necessary to ascertain the precise composition of the soil. This can only be done by a chemical analysis. It is the business of the analytical chemist to do this in such a manner that each constituent of the soil may be separated and its proportions determined.

An approximate analysis of this sort is not difficult to make, and might perhaps be performed by any one so disposed; but since a chemical analysis is of very little use unless it is complete, that is to say, unless everything contained in the soil is separated, and the potash, phosphoric acid, and other more valuable parts of the soil are accurately determined; and as these operations require much care even in the hands of an experienced chemist, we do not think it desirable to describe in any way the process for the chemical analysis of a soil.

Another kind of analysis, often of great service in judging of the capabilities of a soil, is called a mechanical analysis, and requires much less care and accuracy in its performance than a chemical analysis. This kind of analysis has for its object the determination of the relative amounts of organic matter, sand, clay, and lime, and in many cases is all that is necessary to decide important questions in the practical management of soils.

The value of chemical analysis in deciding agricultural questions is often very great, and in many cases at once determines whether a proposed scheme for improvement is calculated to succeed or not. For instance, in the important question of subsoiling, we can at once learn whether it is desirable or not to turn up the subsoil, by making a complete analysis of it: from the result of this

analysis we can decide whether its admixture with the surface-soil is likely to produce improvement or injury. Subsoils often contain poisonous substances, which, if turned up, will of course exercise an injurious effect upon the surface-soil ; on the other hand, valuable fertilizing materials often lie hidden in the subsoil, which might greatly enrich the surface.

Again, the infertility of a soil is often explained by an analysis. The soil may be suffering from the want of some material indispensable to the growth of plants, or it may contain something poisonous to plants ; in either case Chemistry is generally able to enlighten us, and to point out the means for remedying the evil.

Of a soil whose fertility is impaired, we can all pronounce that it wants manuring ; but with the assistance of an analysis we may also learn in what substance the soil is deficient in, or what kind of manure it wants. With this knowledge we may restore its fertility in the most economical manner, by supplying those materials only that are required, and leaving out all the other, in this case, useless materials, always present in compound manures.

By an analysis we may further ascertain whether a soil wants draining or not.

Another question that often arises in the management of clay soils, and one that can be solved by analysis, is whether a clay may be improved by burning or not. In most cases this operation is attended with the best results, the soil being benefited to an extent often equal to that produced by a large dose of manure : in such cases this expensive operation can be advantageously employed, and the money spent upon it will be well laid out. But it sometimes happens that a clay cannot be improved by burning, because it contains no useful materials in a locked-up state, and, consequently, is unable to supply them by any amount or by any method of burning. Hence, in such a case, the operation will be useless, and the money spent upon it wasted. Analysis will at once guide

us in this matter : it will tell us whether a clay will be improved by burning or not, and point out the proper method of burning clays, and the extent of improvement we may expect from it.

Perhaps the most frequently occurring instance of practical benefit conferred by Chemistry upon agriculture is manifested in the assistance it renders in connection with the question of liming. Chemistry tells us in the readiest manner whether a soil wants liming or not, and points out the best plan of proceeding, if it does. If, as often happens, we have a choice of two or three sorts of lime at our disposal, it will also tell us which sort is likely to produce the best effect.

Limestones and marls vary most widely in their fitness for use in this way; many of them contain an excessive amount of magnesia, and on this account are dangerous to use. Others may contain appreciable quantities of the valuable phosphoric acid. On all these points chemical analysis will enlighten us. We may ascertain in a very ready manner if there is enough lime in a soil as follows :—Place a little of the soil in a wine-glass, and add some muriatic acid (this acid is well known, and can easily be procured by the name of spirits of salt). If the earth now bubbles up or effervesces, we may assume that plenty of lime is present in the soil; but if no effect is perceptible, we may infer that the soil is deficient in lime. The lime in soils usually occurs in the shape of carbonate of lime : this, as we have seen, consists of lime and carbonic acid gas in a fixed or solid state. On adding to this combination muriatic acid, the lime unites with this acid, and liberates its former companion—carbonic acid. This gas, in escaping from the mixture, gives rise to the bubbling up or effervescence. This test, it must be remembered, is but a very rough one, and by no means conclusive as to the presence or absence of lime in a soil, yet it will often be found useful as a general test for lime.

CHAPTER IV.

WATER.

All the different kinds of waters found in nature consist of real or pure water, containing different sorts and different quantities of animal, vegetable, and mineral impurities.

Chemically speaking, there is but one sort of water, and this can be separated by suitable means from any description of water, however impure it may be. The distinguishing qualities of rain water, spring water, mineral water, and sea water, and all other kinds of water, are imparted by the foreign matters mixed with, or dissolved in this real or pure water. Before describing the qualities of pure water, it will be well to consider the general properties of ordinary water, and its connection with the other materials of the earth.

Water is found in three states or conditions: as a solid, in the form of ice; liquid, as generally met with; and as a vapour, or in a gaseous form, as steam. In these two latter conditions, water is intimately connected with the economy of nature, and especially with animal and vegetable life. Solid water, or ice, is comparatively unimportant; yet even in this shape, or rather in its conversion into this shape, water exerts a highly beneficial effect on our soils, as noticed in the preceding chapter. Although ice, or solid water, is seen only during a part of the year in this climate, it forms in the polar regions permanent rocks like granite, limestone, or other minerals. In warm or temperate climates, water is generally met with as a fluid; in which condition it is intimately concerned in the operations of organized life. In every stage

of the development of plants, the presence of water is absolutely necessary, and in the various functions of animal life its presence is alike indispensable. In its more bulky condition of steam, water is no less useful and essential in the operations of nature. The vapour of water forms, as we have seen, an important constituent of the atmosphere, and it is in the form of vapour, or, as we shall call it, natural steam, that water gives rise to the beautiful phenomena of rain and dew. Before entering into any explanation of the manner in which these phenomena are produced from the vapour of water, it will be well to make ourselves acquainted with the general properties of steam, and this we shall best do by first directing our attention to artificial steam, or that produced when water is exposed to fire. And here we may remark, that this artificial steam performs a no less important part in our artificial world of manufacturing art, than does the natural steam in the economy of nature; since it supplies us with an unlimited source of strength, and enables us to perform tasks that would otherwise be utterly impracticable, when made to exert its power through the medium of the steam-engine.

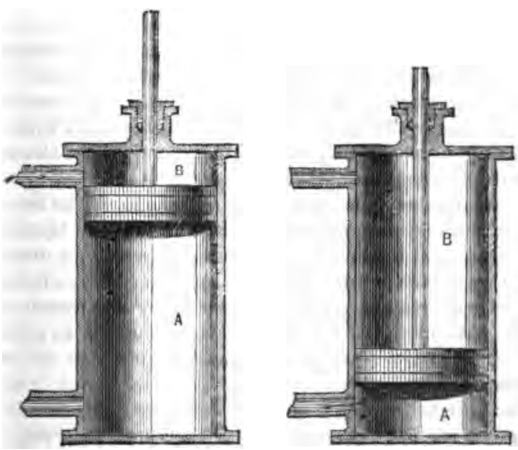
When water is made to boil in a covered vessel, as in a teakettle, the water rises as steam, which quickly fills the vessel, and in a short time escapes from the spout, giving rise to a cloud of white vapour. Steam is nothing more or less than water in the shape of gas, which gas is invisible like the air. It must not be supposed that the white cloudy substance seen to issue from the spout of a teakettle or the escape-pipe of a steam-engine, is steam: the white cloud is water in a finely-divided state, into which the steam is changed on coming in contact with the colder atmosphere. These particles of fluid water being too small to exhibit the transparent appearance belonging to water in larger quantities, form a white opaque cloud, just as glass, which is usually transparent in masses, becomes white like flour when finely powdered.

We may satisfy ourselves that steam is really invisible, by noticing that immediately at the orifice whence the steam issues, the white cloud is not seen, it being only formed when the steam becomes mixed with the surrounding air, or still better, by boiling some water in a glass flask, when steam will rise from the mouth, while the interior is apparently empty.

When a kettle or other vessel containing water is made to boil over a fire, provided the steam can escape, it never gets hotter than the temperature of boiling water: this temperature is found to be 212° of Fahrenheit's thermometer. How is this? We know that a vessel containing no water, under the same circumstances, quickly gets much hotter, and soon becomes red-hot; why does not the kettle and water become red-hot too? Because all the heat that would make it red-hot combines with the water, which passed away as steam; and as long as any water is left, all the heat the kettle receives will be disposed of in this way. Thus we may regard steam as water combined with heat. When water is converted in this manner into steam, it occupies 1,700 times more space than it did when in the form of water. Further, if by any means this steam is deprived of its heat, the water returns to its original shape, that of fluid water, and now occupies 1,700 times *less* space than it did when in the shape of steam: the steam is now said to be condensed. Thus, by condensation, invisible steam returns to fluid water. It is on these simple facts that the prodigious power of the steam-engine depends for its action. The steam-engine is merely a machine contrived to allow the above-named phenomena to display themselves. A very brief explanation of the source of motion in a steam-engine may not be uninteresting. A metal box is constructed, with a tight-fitting division that is capable of sliding from one end of the box to the other: thus the box is permanently divided into two portions, each portion diminishing or increasing in size as the division moves

from one end of the box to the other. The box we have described is the cylinder, as it is called, of the engine; the tight-fitting but sliding division is called the piston. This piston is the only part of the entire machine that the steam puts in motion; all the other parts of the engine are contrivances for supplying steam to the cylinder at the proper time, or for communicating the motion of the piston to other parts of the machine. Let us see how the above properties of steam cause the movement of the piston.

Suppose the piston to be moved to one end or to the top of the cylinder, and the compartment marked A in the annexed engraving to be filled with steam, and that by suitable means this steam is rapidly condensed, it will now occupy 1,700 times less space; or, to be less precise, we may assume this compartment will suddenly become empty. Suppose again more steam is admitted at the other end of the cylinder, or to that compartment marked B. By its pressing with all its force on the upper side of



the piston, and there being now nothing on the opposite side to oppose its progress, the piston is moved forwards or downwards, as the steam enters and fills this portion of the cylinder. On this steam being in its turn condensed in the same manner, and more steam being admitted to the lower compartment, the piston is moved back again to its former position; and so by a repetition of these acts, the motion of the piston from one end of the cylinder to the other is maintained.

Without entering into any explanation of the prodigious power or strength of the steam-engine, we may remark that the force with which the piston moves depends on the pressure of the steam employed, and the extent of surface the piston exposes to the steam. The beauty of the steam-engine lies in the fact that its strength, however vast, is perfectly under control.

Steam is formed at all other and much lower temperatures than that at which water boils. Water exposed to the air, evaporates and becomes steam at all temperatures; even ice and snow evaporate to a small extent. The rate of the evaporation, however, always follows an invariable rule: it is rapid in proportion to the temperature; slower, in proportion as the air is cold. We have already seen that the atmosphere always contains water in this invisible or gaseous condition, and that the amount of water present in the air depends upon the temperature of the earth and the atmosphere.

The same laws of condensation affect the steam formed at these lower temperatures, as in the case of that produced from boiling water; in either case a certain amount of heat is requisite to preserve the water in the form of steam of corresponding density; and if by any means this heat is withdrawn, the water again separates as a fluid. These facts help to explain the phenomena of rain and dew.

In hot, dry, summer weather, the amount of heat pervading the air is very great, and a corresponding amount

of water is dissolved by this heat, or, in other words, a great deal of natural steam exists in the atmosphere. If such air comes in contact with any colder object, it is cooled down, and now, being deprived of a portion of its heat, it is no longer able to retain all the water it held in solution; so that a portion of this water is condensed, or deposited in a liquid form upon the cold object. This deposition of fluid water upon any solid object we call dew. We may produce dew at pleasure by exposing any cold object to warm and moist air. When a glass of cold spring water is exposed to the air in summer time, a copious deposit of dew is soon formed on the outside of the glass, produced from the steam in the air being condensed by the cold glass in the manner above described. The same thing takes place when we breathe upon a looking-glass or polished metallic surface; the water dissolved in our breath in this case, furnishes the fluid water or dew that is deposited on the glass or other cold surface.

In the same manner, on a larger scale, water is deposited on the cool surfaces of the leaves of plants and other objects at the earth's surface, giving rise to the pearly drops of dew.

During the day, every object exposed to the sun becomes heated; on the departure of the sun, in the evening, these objects begin to lose the heat they have absorbed during the day: it flies off or radiates in all directions, until, on their becoming cooler than the surrounding air, dew begins to fall, or, in other words, the steam of the air is condensed on the colder surfaces of the objects exposed to it.

And here we must notice another beautiful natural law that regulates the deposition of dew, and prevents its being wasted on objects that can make no use of it, and thus reserves a larger quantity for growing vegetables, which eagerly drink it in, and appropriate the refreshing dew. We must all have noticed that grass and herbage are often wet with dew, while the earthy sur-

face of paths and roads is still dry. This is because dew is always deposited first and in greatest abundance on those objects which cool first. The leaves of plants belong to this class of bodies: they soon get hot on exposure to the heat of the sun, and as soon get cold again when the sun goes down. With earthy materials, as stones, gravel, and soil, the case is very different: these substances are slow to receive heat or to become warm; but when warm, are as slow in cooling. Hence these objects retain the heat of the day till late in the evening, and receive but little, if any, of the falling dew.

When a body of warm air, containing a great deal of moisture or natural steam, comes in contact with another body of colder air, some of the steam is condensed and separated, as in the formation of dew; but as in this case there is no solid object to receive the particles of liquid water, it remains where separated in the shape of minute white globules, and forms what we call mists or fogs. In cold weather, every breath we exhale forms in this manner a little cloud of white vapour: when we breathe on a cold glass, the water of our breath separates in dew; but when we breathe into cold air, it separates in the form of mist.

When a larger quantity of water is separated in the same manner, at a higher elevation, the particles of water collect in drops, and rain is formed, which, in falling to the earth, removes the dust and other extraneous matters floating in the air; thus at the same time purifying and cleansing the atmosphere and enriching the earth.

The quantity of rain that falls in different localities varies exceedingly, being influenced by the physical character of the district, as well as by certain general laws. The chief of these laws is what we might infer from the above statements; viz. that the amount of rain is greater in hot climates than in temperate and cold ones. It is often a matter of interest to ascertain the

quantity of rain that falls in a particular spot. This is done by means of an instrument called a rain-gauge. It is simply a vessel for receiving the rain from a given extent of surface, and preventing its loss by evaporation until measured in a cylindrical glass, whose divisions indicate the amount of rain that has fallen in the space exposed by the gauge. The amount of rain measured in this way is generally stated in inches; so that in reading results of this amount, we are to understand that a quantity of rain has fallen that would cover the entire surface of the ground to the depth stated.

In this country the average annual fall of rain is about 28 inches. This quantity varies in different seasons and in different parts of England, being greater on the west side of the island than on the east. At London the average fall of rain during the year is about 22 inches; at Liverpool 33 inches. The quantity of rain becomes larger as we approach the equator, and in parts of the East Indies the quantity of rain during the twelvemonth is as much as 190 inches, or nearly 16 feet. In this and other temperate climates the fall of rain is pretty evenly distributed throughout the year, but in tropical climates the rain falls during periodical wet seasons, in the intervals of which, with the exception of occasional storms and hurricanes, dry weather can be depended on. The observance of atmospheric phenomena, constituting the science of meteorology, is a matter often too little valued by persons generally: this is the more to be regretted, as it seems probable that by cultivation this science is capable of imparting valuable practical information as to the future state of the weather.

The water of dews and rain is the purest sort of water met with in nature; but even this contains impurities,—foreign matters the rain-drops have collected in their passage through the air. Some of these impurities have been already noticed as substances useful to vegetation.

Of course the rain that falls in the neighbourhood of

large towns cannot be included in the above statement; as the atmosphere of these places is loaded with smoke and other abominations, it follows, that the rain falling in these localities must be very remote from anything like purity.

By imitating the formation of dew, or by condensing steam in vessels where the newly-formed liquid water has no opportunity of meeting with foreign matters that can contaminate it, we obtain pure water. Whenever steam is condensed under these circumstances, the resulting water is free from all solid impurities.

This operation is called distillation, and is carried on in vessels called "stills,"—the same kind of vessel used for the distillation of spirits, and for other purposes in the arts. The water obtained by this process is called distilled or pure water. It is distinguished by the following characters:—In appearance it is much brighter and clearer, and more transparent than water as generally found in nature; it possesses a slight smell and unpleasant taste, or rather its absence of taste produces an unpleasant sensation in the mouth. Further, it leaves no residue or crust of solid matter when evaporated. This pure or real water is the basis of all natural waters, as before stated. We can imitate any kind of natural water (as sea water or mineral water) by adding to distilled water the solid substances found by analysis to be present in the water we wish to imitate.

Distilled or pure water is largely used in analytical chemistry, in medicine, and for photographic and other purposes, where even the slightest impurities of drinking-water would seriously interfere with its use for these purposes.

Let us now proceed to make ourselves acquainted with the chemical characters of this pure water, and ascertain its composition and its behaviour towards other substances.

For a long time no one conceived that water contained anything different from itself, or, in other words, was a

compound substance; but such has been found to be the case. This discovery was made by the distinguished chemist Cavendish, who at the close of the last century demonstrated that water is composed of two gases, called respectively oxygen and hydrogen. One of these gases we have already described, and would remind the reader that 8 lb. of every 9 lb. of water consist of the ever-present oxygen; the ninth part of water consists of hydrogen, whose properties we will now briefly consider.

Hydrogen gas is invisible and colourless like the air, and, as usually prepared, possesses a slight odour. The most remarkable property of hydrogen is its extreme lightness: it is about fourteen times lighter than the air, and consequently is the lightest substance known.

Hydrogen differs from all the gases we have so far described, by being inflammable: it takes fire when a light is applied to it, and burns with a pale yellow flame, scarcely visible in the daylight, but of intense heat.

Hydrogen is an abundant material of the globe, but is never found in a free or uncombined state. As a fluid, we have seen it forms a ninth part by weight of all the water of the globe; and in a solid form it occurs in considerable proportions in animals and vegetables. In the dry substance of hay, roots, wheat, &c., about 6 lb. of every hundred pounds consist of hydrogen. In food of all descriptions hydrogen is also present, as well as in tallow, oil, wood, coal, and other materials used for fuel.

We have mentioned as one of the properties of hydrogen, its inflammability. Whenever hydrogen is burned, it is undergoing rapid oxidation, or combination with oxygen, in a manner precisely analogous to that described while speaking of carbon and carbonic acid gas. The result of this combination is water, which is always found wherever hydrogen is burned. Hydrogen is generally the companion of carbon in all its adventures throughout the artificial and natural operations going on around us. For instance, in combustion, respiration, decay, and the growth

of plants, hydrogen and carbon are always found in company, and performing the same kind of purpose. The combustion of hydrogen is accompanied by the phenomena of flame; all the flames usually met with, as those of our fires, candles, or lamps, are produced from the rapid oxidation of hydrogen.

Thus our breath contains water as well as carbonic acid gas, and, like carbonic acid, is produced by the combination of the materials of our food with the oxygen of the air we inhale. The combination of hydrogen with oxygen in our lungs is also attended with the liberation of heat: this heat, with that resulting from the formation of carbonic acid, sustains the proper warmth of our bodies. The presence of water in our breath may be shown by blowing through a glass tube; the water is condensed as dew, and soon collects in drops and trickles down the sides of the tube.

By means of a powerful current of electricity, water may be separated into its constituent gases, oxygen and hydrogen. The quantity of hydrogen produced is always twice as much by measure as that of the oxygen. Hence we learn that two measures of hydrogen are combined with one measure of oxygen to form water. This decomposition of water by electricity is one of the most beautiful chemical experiments.

To decompose water, we have always to employ powerful chemical agents. This is because the gases are held together so firmly as to resist all ordinary means of separation. Yet, difficult as the operation is to us, with all the appliances of science, the same operation is constantly going on in the leaves of the humblest plant. Plants decompose water as well as other still more powerful mineral combinations, as sulphuric acid, phosphoric acid, carbonic acid, &c., in the cells of their leaves. From the water decomposed in this manner plants derive the hydrogen, which, as above stated, forms a considerable portion of their substance.

Pure water can also be formed by burning together its constituent gases, oxygen and hydrogen, in the proportion above named. If this mixture is made to burn slowly by a suitable apparatus, a flame of intense heat is obtained, called the oxyhydrogen blowpipe-flame; if, on the contrary, any quantity of the mixture is lighted, it explodes with fearful violence: hence this mixture is called explosive gas. The production of a compound in this manner, by putting together its constituents, is called synthesis; the reverse of this process, or the taking apart, is the more common chemical operation called analysis. When a compound like water, for instance, will admit of its composition being demonstrated by both these operations, its composition is established with the greatest certainty. In this manner we can imitate the production of most mineral products; but organic substances, or those of animal or vegetable origin, cannot be produced in this manner. We can analyze them, or take their constituents apart with comparative ease, but all attempts to put these constituents together again, with the expectation of reproducing the original compound, will utterly fail. This constitutes an important distinction between organic and mineral substances.

Another property of water must now be noticed, which, although not strictly a chemical quality, is yet more than a mechanical one: we allude to the solvent power of water, or its property of taking up and dissolving other substances. When we mix salt or sugar with water, it dissolves, and soon entirely disappears. The sweet taste of the sugar or saline taste of the salt is transferred to the water, which is now said to be a solution of the sugar or salt.

In this way a large number of substances can be dissolved in water to a greater or less extent. Sugar and salt are easily-soluble substances, because a small quantity of water is sufficient to dissolve a considerable bulk of either; but many of the substances that are soluble in

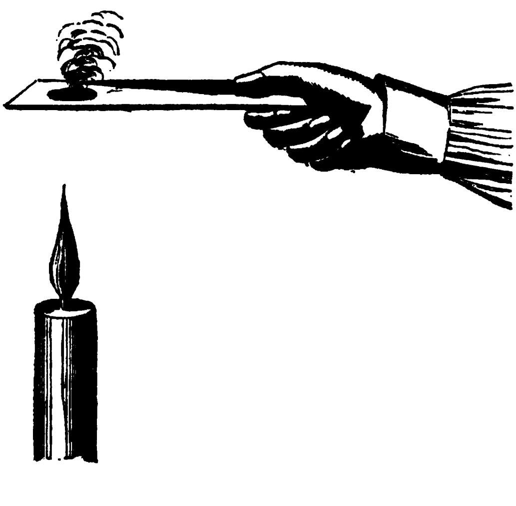
water are but difficultly soluble, a small quantity only being dissolved by a large quantity of water. It is this solvent power of water that prevents it being found in a pure state in nature. Even the rain-drops in falling through the air meet with certain soluble substances, and dissolve them: hence rain water, although the purest kind of natural water, yet contains substances dissolved in it. Again, the rain water, in soaking through the earth, meets with mineral matters, some of which are dissolved and carried away. Thus the water of streams and rivers always contains some of the soluble matters of the ground through which it has passed.

When chalk or earth is mixed with a considerable quantity of water, the bulk of the solid soon settles to the bottom, but the liquid remains muddy; and even after standing some time, the water is still far from clear. The fine particles mixed with or suspended in the water in this manner, must not be confounded with substances that are dissolved in it. When solid matter is merely mixed with or suspended in water, it can be separated from the water by long standing or by filtering; on the contrary, a solid when dissolved in water will never settle by standing, neither can it be separated by straining, because it passes through the finest pores of the filtering material, and will be carried wherever the water can penetrate. Moreover, solid particles, when merely suspended in water, can always be recognized by our sight,—even when their quantity is minute, they are indicated by a muddiness or want of transparency in the water; whereas, solids that are dissolved in water do not in the least interfere with its transparency and brightness.

It is in the character of a solvent, that the value of water in relation to organic life is most displayed. As we shall learn when inquiring into the structure of plants, it is by means of this property of water that plants are supplied with a large proportion of the materials requisite

for their growth. In the bodies of animals it is also by means of this property of water that the nourishing solids of the food are conveyed to every part of the animal frame.

To continue the above-mentioned familiar example of solution ;—if we evaporate or boil away until none is left, the water to which salt has been added, the salt will be recovered in precisely the same condition as before dissolving in the water. In the same manner, all natural waters leave behind, when evaporated to dryness, as this process is called, the solids they had dissolved. We may avail ourselves of this fact to ascertain in a rough manner the relative purity of different sorts of natural water. We can apply this test by evaporating two or three drops of the water to be tested on a slip of window-glass, or a bit of tin plate, holding it over a lamp or candle in the position shown in the engraving. The water is soon



volatilized, and leaves behind all the solid impurities it contained. These are left as a crust or residue on the glass, which is of course abundant in proportion as the water is impure. Pure or distilled water, tested in this way, will be found to leave no residue; rain water will leave very little, river water still more; spring water generally yet more than the waters of streams or wells; while sea water will leave the largest quantity of solid matter. By this test we may satisfy ourselves that clearness and transparency are no criterion of the purity of water. In this manner we can judge of the amount of solid matters dissolved in water, and of course learn something respecting its character or quality.

Rain water, river water, and sea water, and some other sorts of natural waters, differ greatly in their qualities. The two former can generally be used for domestic purposes, while sea water is always totally unfit for drinking in all parts of the world. The water of springs varies considerably in different localities. This is because the rocks and strata through which spring water passes vary most widely in the quantity and quality of the soluble matters they contain. If a stream of water finds a channel through a bed of rock or mineral containing some particular soluble substance in large quantity, the water dissolves the substance and partakes of its qualities. In this way the various mineral waters are formed.

Water can also dissolve gases as well as solids: the refreshing taste of spring water, and, in a less degree, of other kinds of natural waters, is due to the gases dissolved in them. These gases found dissolved in water are generally carbonic acid gas and the gases of the atmosphere. Other gases are occasionally found in spring water, which impart to it peculiar qualities. For instance, the water of Harrogate is impregnated with an offensive gas called sulphuretted hydrogen. The prevailing gas found dissolved in spring water is carbonic acid gas; and it is somewhat strange that this gas, although

injurious to animals when inhaled, seems to exert a contrary effect when taken into the stomach; being at least harmless, if not beneficial, when received in this manner.

We swallow large quantities of carbonic acid dissolved in the beer we drink. The freshness of recently-drawn beer is due to the carbonic acid it contains: bottled beer, champagne, and other effervescing drinks, contain a large quantity of carbonic acid dissolved in them. On liberation from the closed bottles where these liquids are confined, a part of this gas escapes, and gives rise to the bubbling up or effervescence.

On boiling, the gases dissolved in water are expelled. It is for this reason that water that has been boiled is flat and insipid to the taste; for the same reason, distilled, or pure water, is actually unpleasant to the taste.

Water also dissolves organic matter of animal and vegetable origin. The green colour of the stagnant water of ponds and ditches is due to substances of this kind in different stages of putrefaction; and as these impurities are generally accompanied by others still more offensive, as funguses, animalcula, &c., water of this sort is wholly unfit for domestic purposes.

We will now enumerate the more interesting properties of each of the common kinds of water.

Rain water is, as we have said, the purest sort of natural water, and if collected in an open district, in a clean vessel, before it comes in contact with the roofs of houses, or other sources of contamination, it is nearly pure water, and contains only those foreign matters that are found floating in the air. Amongst these substances, the salts of ammonia, before mentioned, are important. It is to the presence of these salts, added to the uniform and gradual distribution of water of the same temperature of the air, that the refreshing effect of rain on growing plants must be ascribed.

The water of streams and rivers contains a great many substances in solution, collected from the soil through which it has soaked; and the qualities of this kind of water will, of course, be influenced by the character of the land through which it has drained. The water of streams and rivers is occasionally found more or less muddy, and containing solid matter suspended in it. This mud is the finer particles of the soil, washed up and carried away, from the land over which it has flowed: on standing, these solid particles are again deposited. In this way we can to some extent account for the good effects generally seen to follow the flooding of land by water, either naturally, as on the banks of rivers subject to inundation, or artificially, by the process of irrigation. But the deposition of mud is not sufficient to account for the striking improvement often observed in land that has been exposed to the action of water. Water acts in this way chiefly through the substances dissolved in it. These will generally be the salts of lime, potash, phosphoric acid, sulphuric acid, and other mineral matters that are known to promote the growth of plants. As it is known that earth, especially clay, is capable of extracting from water any fertilizing salts it may contain in solution, and as many natural waters contain appreciable quantities of these solids dissolved in them, we can in this way account, to a great extent at least, for the increased fertility consequent on the flooding of land by water. Again, an important mechanical effect is exerted by water in large quantities upon land.

By saturation with water, the ground will be consolidated, and its particles become better incorporated, so that on the withdrawal of the water a loose soil will be left in a better mechanical condition than it was before the water was admitted. Again, the air will now penetrate more freely to all the cavities of the soil vacated by the water, and will act more vigorously in decomposing the organic and mineral substances there present; thus rendering

available a more copious supply of food to the growing plants. The fact of timber and other organic matters decaying most rapidly when alternately immersed in water and exposed to the air, may help to explain this effect of water in the process of irrigation.

Rain water and river water are generally "soft" waters; that is to say, they contain nothing that interferes with their use in washing. When soap is used in soft water, the soap dissolves in the water, and exercises its cleansing effect in the following manner:—Soap is a weak combination of fatty matter, generally tallow with some alkali, as soda. On dissolving in water, the alkali of the soap, in virtue of the property already noticed as common to all alkalies, dissolves the animal matter of the dirt, and at the same time a thin surface of the skin to which the foreign matters are attached: the violent action of the alkali is subdued and modified by the fatty matter also present.

Spring water generally contains a larger quantity of mineral matters than the above-named kinds of water; it also contains more gases dissolved in it. The prevailing solid of spring water is lime, or more properly, carbonate of lime; and the gas with which spring water is usually impregnated, and which gives rise to its sparkling appearance and pleasant taste, is carbonic acid gas.

It is this lime dissolved in spring water that renders it "hard" and unfit for washing. When hard water is used with soap, the lime absorbs the soap as fast as it dissolves, and forms with it an insoluble compound, in which the soap is unable to exert its ordinary detergent properties. Hard water can only be made soft by removing the lime that it contains. This can generally be done—1. By exposure for a considerable time to the air; 2. by boiling; 3. by adding soda, or rather carbonate of soda; 4. by adding lime-water, or caustic lime dissolved in water. Before we can understand how the

water is "softened" by these means, we must state more precisely the cause of the "hardness."

It will be remembered that carbonate of lime, or chalk, is insoluble in water: it separates from water as soon as formed, as in the experiment for showing the presence of carbonic acid in the breath.

If, however, more carbonic acid is added to the water than will form chalk with the lime, the chalk now redissolves in the water. We may convince ourselves of this fact by extending the experiment above referred to. If the carbonic acid produced by limestone or marble is made to pass through lime-water, it first forms the white milky particles of chalk, but if allowed to pass through for some time after the chalk is formed, the chalk dissolves again—it disappears, and the liquid becomes clear. Thus we learn that water containing an excess of carbonic acid gas is capable of dissolving a solid substance that is otherwise insoluble; in the same manner many other insoluble compounds are rendered soluble by carbonic acid. This property of water impregnated with carbonic acid is especially deserving of notice, as it is intimately concerned in the supply of several of the mineral-food constituents to plants, and will be referred to in a following chapter.

On boiling the clear solution of chalk obtained by the above experiment, the excess of carbonic acid is expelled, and the chalk again separated in an insoluble form, or is precipitated, as chemists say. Most hard waters contain chalk dissolved in this manner by carbonic acid. When they are boiled, this gas is expelled, and the chalk is separated. In this way is explained the deposition of calcareous matter in our teakettles and the boilers of steam-engines: whenever spring water is boiled, an incrustation is generally deposited from this cause. The same effect takes place more slowly when the water is exposed to the air: the excess of carbonic acid gas escapes, and the carbonate of lime is separated.

The softening of hard water by the addition of lime (ridiculous as it may at first seem to add lime to water already hard from the presence of this material) may be explained as follows :—The caustic lime added takes up the excess of carbonic acid gas which keeps the carbonate of lime in solution, to form more carbonate of lime ; this, with that originally present in the water, is now separated, and settles by standing. This means of softening water can only be cautiously employed, since the addition of too much lime does more harm than good ; it is, however, with proper care, a valuable means of softening water, and is extensively adopted on a large scale. These means of softening water can only be employed when, as is more commonly the case, the hardness of the water is due to the presence of carbonate of lime. Hard water is occasionally found in which sulphate of lime, or plaster of Paris, is the cause of this quality. In this case, the use of some alkali like potash or soda is the only remedy : the addition of these substances in all cases greatly facilitates the action of the soap. Hence the practice of adding pearl-ash or soda to water in washing.

Spring water that contains in solution substances that render them unfit for domestic use, constitute the mineral and medical springs. Of these the chalybeate springs are most common : they contain the protoxide of iron above described. Others contain sulphate of magnesia, sulphate of soda, &c. ; and a few contain substances valuable as medicines.

Well waters vary in quality between spring and river water. While some wells are supplied by natural springs, the greater number receive their water from the drainage of the surrounding soil. From the stagnant condition of well water, it is generally of inferior quality to that of rivers or streams, and is often unwholesome, or even poisonous, from the presence of a large quantity of fungi, animalcula, &c., bred from the putrefying animal and

vegetable matters which the water of wells often contains in greater or less quantity. The water of wells, especially in towns, is often rendered unfit for domestic use by the sewage finding its way into the wells. For this reason, in sinking wells, especial care should be taken that a proper distance intervenes between them and the drains from stables, dwelling-houses, and all other sources likely to contaminate the water of the well. Well water, and that from other sources, often owes the greater part of its impurities to the solid matters floating or suspended in it. In these cases, filters may be used with great advantage; but it must be recollected that filters are powerless in removing any kind of impurities dissolved in the water.

Sea water differs from all other sorts in being totally unfit for domestic purposes, and by the large amount of soluble matters it contains. Of these, we all know that common salt is the most abundant: 1,000 lb. of sea water contain about 35 lb. of solid matter; and of this quantity 27 lb. are common salt. A great number of other soluble substances exist in sea water; in fact, the sea is the common receptacle for all the soluble matters of the globe. Water, in the shape of vapour, is constantly rising from the surface of the sea, and is carried over the land by the clouds; these, sooner or later, discharge this water in the shape of rain, and this, in its passage back to the sea by streams and rivers, bears with it a quantity of soluble matter, derived from the soil through which it has drained.

Notwithstanding the water of the sea is so impure, it may be purified by distillation. A knowledge of this fact might have saved numbers of persons from intolerable suffering, and even death from thirst, when deprived of fresh water at sea. A distilling apparatus might be constructed by almost any one on an emergency from a teakettle, or other vessel of the sort; and the only limit to the quantity of drinkable water that could now

be obtained would depend on the amount of combustible material at command.

Water is decidedly one of the most valuable of Nature's gifts: it not only contributes to our happiness and comfort in so many different ways, but is intimately associated with our very existence.

In every stage of the production of every sort of agricultural produce, water plays an important part: in the germination of seeds, the subsequent growth of the plants, the development of their seeds and bulbs, the presence of water is absolutely necessary. In ordinary articles of diet, water forms a proportion surprisingly large to persons unaccustomed to chemical wonders. In raw meat, 78 lb. of every 100 lb. are water; potatoes contain 72 per cent. of water; in cattle-food, a still larger quantity (in Swedes, for example, there is 88 per cent. of water, while in white turnips, the proportion of water is often as high as 91 per cent., or 9 lb. only of real food in 100 lb. of turnips). After these statements, we may not be surprised to hear that the greater part of our own bodies consists of water: a man weighing 154 lb. contains 116 lb. of water and 38 lb. of dry substance.

CHAPTER V.

CHEMISTRY OF THE PLANT.

Having now made ourselves acquainted with the composition of the soil, of the air, and of water, the sources whence plants derive the materials of their growth, let us trace the formation, from these materials, of the products of vegetable life, particularly those which constitute the food of man and animals. When a growing plant is removed from the soil and exposed to the sun and wind,

it quickly droops, withers, and finally shrinks up to a much smaller bulk and weight than it possessed when recently gathered. This loss of substance is due to the evaporation of the water, which, as before hinted, forms so large a proportion of all living vegetables. Again, if this diminished substance of the plant left after drying is exposed to fire, nearly all of it burns away or disappears, leaving nothing behind but a little ash or mineral matter. The portion of the plant that suffers destruction by burning is called the organic part, because it consists of various compounds produced by the process of vegetable growth, from materials supplied from some of the sources above mentioned. The constituents of this organic part of the plants are carbon, hydrogen, oxygen, with small quantities of nitrogen. By heating, these materials pass off as smoke and invisible gases: hence the disappearance of the greater part of the plant on burning. These materials exist in the plant, grouped together in all sorts of positions and proportions, giving rise to the numerous substances of vegetable origin we see around us. Wood, starch, sugar, fat, linen, cotton, and a multitude of other equally well-known materials, consist of nothing but the three former of these elements, in each case differently arranged. The fourth constituent, nitrogen, occurs chiefly in the choicer parts of plants,—the seeds, and other parts of their structure most valuable as feeding materials.

The ash left on burning plants consists of the mineral substances extracted from the soil during their growth; and these, not being volatilized by heat, are left behind after the vegetable matter is consumed. This portion of the plant is called the mineral or inorganic part of it, and consists of nearly all the materials described as belonging to the soil. The general composition of plants, that is, their proportion of water, organic matter, and ash, will be understood by a glance at the following table :—

GENERAL COMPOSITION OF VEGETABLE PRODUCE.

(*Stated in one-hundred parts.*)

	WHEAT.		TURNIPS.		CABBAGE.
	Grain.	Straw.	White.	Swedish.	
Water	12·26	14·23	90·43	89·46	86·28
Organic or combustible matter; consisting of carbon, hydrogen, oxygen, nitrogen	85·99	78·30	8·95	9·52	11·85
Ash, or mineral matter; consisting of nearly all the constituents found in the soil	1·75	7·47	·62	1·02	1·87
	100·00	100·00	100.00	100·00	100·00

For a long time no notice was taken of this small quantity of ash left on burning plants; no one supposed that it was in any way essential to the structure of the plant, or had taken any part in its development. Until comparatively recently, the impression concerning the ash of plants seemed to be that it consisted of mineral substances accidentally conveyed to the plant from the soil. This, however, is not the case. We now know that this ash, or the mineral constituents of plants, although smaller in quantity, is nevertheless as important, or even more so, than the more abundant organic or vegetable portions of the plant; that their presence is not accidental, but necessary to the formation and the existence of the vegetable productions in which they are found. Hence the separation of the constituents of plants into organic and mineral groups is altogether an imaginary division, and made only to suit our convenience in studying their composition. It must be recollected that no such division exists in nature, both mineral and organic substances being equally indispensable to the development and to the identity of the several vegetable compounds of which the plant is built up; that, in short, vegetables, or more strictly the organic principles of vegetables, are combinations of large

quantities of certain constituents of the air and of water with small quantities of the mineral compounds of the soil.

That the ash or mineral constituents of plants is really essential to their growth, and not, as formerly supposed, merely of accidental occurrence, is established by the following facts :—

1. The proportion of ash or inorganic materials, although subject to slight variations that need not be accounted for here, is generally constant in the same kind of plant, and in the various parts of the same plant.

2. That while certain mineral substances are common to several families of plants, their amount and relative proportion vary with each tribe of plants; or, in other words, particular inorganic materials predominate in particular tribes of plants. For instance, in the cereal crops, as wheat, barley, oats, &c., the prevailing mineral consists of silica. Again, in plants of the pea tribe, or leguminous plants, as clover, pease, beans, &c., lime is the predominating mineral constituent.

3. These differences in the composition of the ash of plants are not materially affected by the character of the soil on which the plants have grown. To continue these examples, the wheat plant is always found to contain a large proportion of silica, although it may have been raised on a lime soil, and the clover or pea will also contain large proportions of lime, even when grown on a sandy or clay soil. On this fact is based the classification adopted for cultivated plants, in which they are arranged in groups, named after the prevailing constituent of their ash; and called silica plants, lime plants, potash plants, &c.

4. Since each tribe of plants requires more particularly a certain kind and a certain quantity of mineral matters for its development, it is clear that unless a soil is capable of furnishing these materials in sufficient quantity, this tribe of plants will not flourish upon it; and if the soil is wholly destitute of the particular mineral substances required by

the plants, they refuse to grow, or, at least, to come to perfection.

These remarks will be better understood by a careful examination of the following table:—

COMPOSITION OF THE ASH OF

	WHEAT.		CLOVER.	SWEDISH TURNIPS.
	Straw.	Grain.	Leaves & Stems.	Bulbs.
Potash	12·14	29·97	24·928	36·98
Soda	·60	3·90	3·039	6·76
Magnesia	2·74	12·30	12·176	3·61
Lime	6.23	3·40	34·908	11·14
Phosphoric acid	5·43	46·00	7·352	9·74
Sulphuric acid	3·88	·33	3·718	12·43
Silica	67·88	3·35	1·313	3·43
Peroxide of iron	·74	·79	1·470	1·09
Chloride of sodium	·22	·09	11·096	7·85
Chloride of potassium	—	—	—	·59
Carbonic acid	—	—	—	6·38
	99·66	100·00	100·000	100·00
Percentage of ash in dry	6·02	1·93	10·53	5·91

The mineral constituents of the ash, and the carbon, hydrogen, oxygen, and nitrogen of the organic portion, are said to be the ultimate principles of plants, because these are the fundamental constituents of all plants, into which they can be separated by chemical analysis. These materials, existing in the plant, are not endowed with the same properties as we find them possessed of when forming part of the atmosphere, of water, or of the soil from which they have been derived. All their individual properties are put aside, and by the functions of vegetable life they are arranged together in new forms, possessing new properties, altogether distinct from those of any of their combinations we have hitherto described. These compounds are called the proximate principles of plants, and they constitute the natural materials of which all plants are formed. The vegetable productions used as food for

man and animals are to be regarded as mixtures of those proximate principles. In order that we may clearly understand the difference between the ultimate and proximate principles of plants, and the full meaning of the latter term (a distinction that is very necessary to be understood), let us mention an example. The bulk of all plants consists of woody fibre; this woody fibre, or simply wood, is the same substance, whether it occurs in close masses, as in the stems of trees, or as fibrous threads in the stems of smaller plants—the flax-plant, for instance. In this latter form we call it flax, and when manufactured, linen. In the former case we call it timber of various sorts; but from whatever source derived, this woody fibre, when separated from foreign substances with which it is always naturally mixed, possesses the same qualities, and is chemically identical. Woody fibre is one of the most abundant of the proximate principles of plants. If we further examine this substance and subject it to other more powerful means of separation, we find it to consist of carbon, hydrogen, and oxygen, with a small quantity of mineral matter, or ash. These are its ultimate constituents. Of the same character, but in less abundance, we find hosts of other compounds in the vegetable world; but luckily for us, the number of them essentially concerned in the vegetable productions used as feeding materials is not large. While nearly every tribe and variety of plants contain some principle peculiar to itself, which gives rise to the distinguishing characteristics of its produce, they also contain a number of other principles common to all plants. Compounds of the former class generally constitute but a minute proportion of the substance of the plant, and may be omitted in all practical considerations; the latter kind are those of which its bulk and weight consist, and by which its value as a feeding material is regulated.

The number of proximate principles to which we need direct our attention is about twelve or fourteen. These

are divided into two classes :—1. Principles which consist of the three elements, carbon, hydrogen, and oxygen (exclusive of the small quantity of ash), as in the above-mentioned example, woody fibre. These are called non-nitrogenous or carbonaceous compounds, and with one or two exceptions, are also called respiratory, heat-giving, or fat-producing substances, on account of the part they perform in the animal organism. 2. Principles which contain, in addition to the elements just mentioned, nitrogen, as well as smaller quantities of the rarer mineral substances phosphorus and sulphur. These compounds are called nitrogenous, sanguineous, or flesh-forming principles, on account of the important office they perform in relation to animal life.

Non-nitrogenous, Heat-giving, and Fat-producing Principles of Plants.

The compounds belonging to the group of non-nitrogenous and fat-giving principles, to which we need direct our attention, are the following :—

Lignine or woody fibre has already been noticed. It is by far the most abundant of vegetable products, as it forms the bulk of most plants; in wheat, oats, grass, and all cultivated crops, it is more or less abundant. Woody fibre, in a matured state, is useless as a feeding material; it simply passes unchanged through the animal system, and in the case of our domestic animals forms the chief bulk of their solid excrements: hence the amount of this substance materially affects the value of feeding materials. The imperfectly-formed woody matter, as it exists in young plants and in the succulent portions of older ones, is digestible in the stomachs of animals, and seems to be nearly as useful to them as the other members of this group. As it is found that the proportion of indigestible woody fibre greatly increases as the plants reach maturity, we can, to some extent, account for the superior value of

hay that has been cut early, in comparison with hay made from plants that have been allowed to arrive at a more advanced period of their growth.

Starch forms a considerable portion of flour and meal of every sort; it also occurs in potatoes, carrots, and other roots. Sago, tapioca, arrowroot, &c., consist almost entirely of starch. In a dry state, starch forms white glistening particles, which, when examined under the microscope, present the appearance of little groups of knobs or clusters of irregularly-shaped bodies. Starch is insoluble in cold water; by heating, starch is converted into a sort of gum called dextrine. This substance is at present manufactured on a large scale, and has nearly superseded the use of the natural gum arabic.

Sugar is present in the juice of most plants, and in particular plants, as the sugar-cane, maple-tree, and beet, occurs in a quantity sufficient to admit of its profitable extraction. Of the plants usually cultivated, sugar occurs in largest quantity in the carrot, mangold, Swede, and turnip.

Gum, Mucilage, Pectin, are all more or less abundant in cultivated produce, and possess several properties in common. Mucilage occurs in particular seeds, as in linseed; the gelatinous mass obtained on mixing linseed meal or linseed cake with water, is caused by the mucilage of the seed.

Oil or fatty matter is found in the seeds of many plants, as linseed, rapeseed, &c. These seeds, even when deprived of the greater portion of their oil by pressure, still retain enough of this substance to render them useful as a feeding material: the various oilcakes used for fattening cattle consist of seeds in this condition. These several substances possess many properties in common, and with the exception of indigestible woody fibre, seem to be of nearly equal value in the animal organism.

Of these compounds, the greater part of the dry substance of vegetable productions used for food consists, and

when received into the animal system, they become the fuel before noticed as necessary for sustaining the animal heat in the process of respiration. It will be remembered that the breath of animals effects the combination between combustible materials in the blood and the oxygen of the atmosphere; and as in this process a certain amount of heat is liberated, the animal heat requisite for the animal functions is kept up. These combustible materials, which may with great propriety be called animal fuel, are the starch, sugar, oil, &c., in food. The greater portion of the food consumed by animals is required simply for the purpose of supplying heat to the body by undergoing oxidation in the lungs. The products of this oxidation are the same as if these materials had been burned; in either case, carbonic acid gas and water are formed, which, in the case of animals, pass off in the breath exhaled. Thus the chief part of the food taken into the animal system is disposed of through the lungs, and its constituents are returned to the atmosphere, in the same condition as before being manufactured by the plants. When a larger quantity of this kind of food is taken by an animal than is required to sustain the proper heat of its body, the excess is stored up in the shape of fat. Thus an animal confined in a small space and taking no exercise, becomes fat, from the formation of this material from the food that would otherwise be consumed by exertion. All of these respiratory compounds can thus be converted in the animal organism into fat, but with different degrees of facility: the nearer these substances approach to the character of fat, the sooner and readier they become fat when digested by an animal. For this reason, vegetable fats and oils are found most conducive to the formation of fat, when consumed by animals. This we can easily understand. We should naturally expect that the conversion of linseed oil, for instance, into animal fat, would be a simpler process than the production of the same material from sugar or starch. In this way is

explained the superior efficacy of the different oilcakes, compared with other kinds of food in the fattening of cattle. On the contrary, when the quantity of respiratory compounds is deficient in the blood of animals, either from insufficient food being supplied, or, what amounts to the same thing, inability to digest the food taken into the stomach, the animal system suffers from want of heat, and cold is felt; the warmth required for the proper maintenance of the animal functions is wanting, and the health more or less interfered with. Moreover, unless a due amount of combustible matter is present in the lungs for the oxygen of the air to act upon, the surfaces of the lungs are themselves wasted by the oxygen of the air. As the heat of the body is in direct proportion to the quantity of respiratory compounds consumed in the lungs, and as a certain amount of heat is necessary for the proper performance of the functions of the animal system, it is clear that a healthy animal will require more heat, and consequently more food, in cold weather than in warm weather. In the same manner may be explained the well-known fact that animals exposed to cold winds consume more food than when sheltered.

Thus we may conclude that the members of this group of organic compounds, when used as food, act either by supplying the animal system with warmth, or by furnishing material for the formation of fat, but are unable to impart nourishment, in the proper sense of the word: they are incapable of restoring the waste the body undergoes by exertion, or of supplying material for building up the bones, muscles, nerves, and other parts of the animal frame. For this reason they do not of themselves constitute wholesome food. An animal fed on these materials only, quickly perishes for the want of the—

Nitrogenous or Flesh-forming Principles of Plants.

As already mentioned, the nitrogenous principles of

plants constitute the smaller and choicer portion of all vegetable substances used for food. These compounds differ from the preceding ones in having a less simple composition. They contain, in addition to carbon, hydrogen, and oxygen, nitrogen, as well as smaller quantities of the rarer mineral substances sulphur and phosphorus. They all closely resemble in character the animal substance called albumen, or white of egg,—hence they are sometimes called albuminous compounds; and, from the fact of their being the more valuable principle of food, or that portion of it that supplies animals with the materials of which their blood, flesh, and structure are made, these compounds derive their more common name of flesh-forming principles. The names of these compounds are, vegetable albumen, vegetable casein, gluten or vegetable fibrine, and legumine.

When wheaten flour is moistened and made into a dough, and washed and kneaded in a stream of water, the starch, that forms a large proportion of flour, is carried away by the water, while an elastic, stringy mass remains. This is gluten, or animal fibrine, and may be accepted as a good example of all the compounds of this class. Vegetable albumen is found in the juice of cabbage and other produce, and resembles the white of egg. Legumine is a peculiar compound, found in pease, beans, clover, and other leguminous plants, and is closely allied to the cheesy matter or casein of milk. All these compounds resemble one another most intimately, and possess several properties in common, and may be regarded as equally valuable in the animal economy. For this reason some chemists regard them as modifications of one principle, which they call protein. Hence another name by which these bodies are known,—protein compounds.

We annex a table showing the proportions of these substances in several kinds of vegetable produce.

PROPORTION OF FLESH-FORMING PRINCIPLES AND WATER IN FOOD.

	Gluten (in one hundred parts).	Water
Wheaten bread	6	45
Wheat (whole grain)	12	16
Bran (outer and inner skins)	16	13
Fine flour	10	14
Oatmeal	18	—
Beans	25	12
Rice	4½	12
Potatoes	2	75
Lean Beef	19	78
Cheese	29·45	36·61
Cabbage	4½	86
Turnips	14	90
Carrots	6	87

In the bodies of animals, substances corresponding to each of these vegetable principles are found: they are called fibrine, albumen, casein, &c. For a long time these substances were regarded as peculiar animal products,—combinations exclusively found in the animal system; but such is not the case. It is now known that animals receive these principles ready formed in their food, and that they are in all cases prepared in the first instance by plants. In the case of herbivorous animals, or vegetable-feeders, the class to which most of our domestic animals belong, these compounds are extracted from the food by digestion and other processes, and conveyed to the blood.

The numerous products peculiar to the bodies of animals,—as gelatine,—the substance of skin, tendons, the organic portion of bones, &c.; bile,—the chief agent in the process of digestion; and other animal substances, are all formed from the breaking up or separation into simpler compounds, of the primary combinations supplied by vegetables. In the case of carnivorous animals, these compounds are simply transferred from the flesh of the animals consumed as food to the blood of the consumer.

Hence the process of digestion and assimilation is in this class of animals comparatively simple.

Since it is from these nitrogenous materials that the bodies of animals are built up and strengthened, it follows that the nutritive value of food, as far as its power of forming flesh is concerned, depends on the amount of those substances it contains, provided, of course, they exist in a condition that will admit of appropriation by the digestive organs of the animal that receives this food. In the human system, the most nourishing kind of food is generally well-cooked meat, or the flesh of animals in a state that will admit of ready digestion. This contains all the nutritive principles, as well as the respiratory material, in the shape of fat, in a concentrated, compact form; and in this state food is more easily assimilated by the blood than when conveyed to it in the shape of a bulky vegetable article of consumption.

As it is exclusively from the albuminous materials that the muscles and tissues, wasted by exertion and exercise, can be renovated and strengthened, it follows that the greater the amount of exertion or work an animal undergoes, the larger must be the quantity of these substances that must be given to an animal in order to sustain its condition.

If by any means the quantity of albuminous matters in the food is inadequate to make good the material exhausted by labour, the animal frame suffers waste and emaciation. For this reason, working horses require corn and beans in proportion to the labour they undergo; and if from neglect or otherwise these materials are withheld, or other less-nutritive mixtures substituted, the health and stamina of the animals will inevitably be impaired. In young growing animals, the proportion of these materials in the food must be still larger; since, in addition to material for supplying the waste by exertion, as in the case of the adult animal, a further quantity is requisite for building up the rapidly increasing organs of their structure.

Again, in the case of animals whose system is exhausted by the production of any particular secretion, as for instance in milch-cows, the food supplied must contain sufficient nitrogenous matter to furnish material for milk, in addition to that required by the ordinary waste of the body.

At the same time it must be remembered that the more valuable nitrogenous or flesh-forming principles, like the simpler ones before noticed, are equally unable of themselves to support animal life. A due mixture of the two sorts of compounds is the kind of food intended by Nature to support the health and strength of animals; and for this reason we cannot expect that a departure from this arrangement can be persisted in for any length of time without endangering the life of an animal.

DETAILED COMPOSITION OF VEGETABLE PRODUCE.

(Stated in one-hundred parts.)

	WHEAT.		TURNIPS.		CABBAGE.
	Grain.	Straw.	White.	Swedish.	
Water	12·26	14·23	90.43	89·46	86·28
Flesh-forming constituents	11·64	1·79	1·14	1·44	4·75
Heat and fat-producing substances	68·74	31·06	5·45	5·93	7·10
Woody fibre (indigestible)	2·61	45·45	2·34	2·54	—
Inorganic matters (ash)	1·75	7·47	·62	1·03	1·87
	100·00	100·00	100·00	100·00	100·00

Structure of Plants.

Having described the products of vegetable life that take part in the nourishment of animals, let us now inquire into their production, and endeavour to ascertain how they are formed in the organism of the plant from the materials at its disposal. These, as we are already aware, are the constituents of the soil, of water, and of the atmosphere.

It will be necessary, first, to briefly consider the general

structure of plants, as described by vegetable physiologists. Plants essentially consist of the root, stem, and leaves. The roots and fibres ramify in every direction in the soil, as the branches and leaves do in the air: the stem connects these two systems of organs. The substance of a plant—the greater part of its roots, stems, and leaves—consists of minute tubes or pipes for carrying the sap to every part of the structure. The stem is thus a bundle of parallel tubes, some of which convey the sap from the roots to the leaves, others return the sap from the leaves back again towards the root. The extremities of the roots terminate in soft spongy organs, full of minute pores or openings, which are too small to allow of anything but liquids or gases passing through them: consequently solid matter cannot enter otherwise than in solution.

Through these pores, at the extremities of the roots, water and the substances dissolved in it are constantly absorbed, and conveyed through the inner portion of the stem to the leaves, where, by numberless small vessels, it is spread out over a large surface to the action of the air and light. Here the chemical changes take place that give rise to the production of the organic compounds above described. The sap containing these manufactured materials next passes downwards by the outer layer of tubes, or that which in trees is called the bark, and deposits the materials prepared in the leaf in the various organs of the plant.

Thus the leaf is the most important part of the whole plant, the organ more directly concerned in the production of the different kinds of organic principles. The surface of the leaf is covered by a multitude of pores or openings. Through these pores gases are constantly passing; carbonic acid gas of the air is absorbed; water in the shape of vapour is evaporating. It is chiefly this evaporation of water from the leaf that gives rise to the circulating motion of the sap.

The water constantly evaporating from the surfaces of

the leaves of plants, is supplied through their roots and stems from the moist soil. If this evaporation from the leaves is more rapid than can be supplied by the roots, the leaves droop,—an effect constantly seen during the hottest parts of a summer's day. The same thing takes place when a plant is separated from its root, and this the more rapidly as the surrounding air is warm and dry. We avail ourselves of this circumstance when hoeing weeds during the hot sunshine: the weeds, when deprived of their roots, or removed from the moist soil, quickly wither and perish. Again, a flower plucked from its stem soon droops and loses its beauty, from this loss of water; but if we place its stem in water, some of this water is sucked up, and supplies the evaporation from the flower; so that its freshness is preserved for a much longer period.

The water that is thus constantly passing up through the stems of plants will, of course, carry with it the substances it holds in solution; and since these substances cannot evaporate with the water, they will be left behind in the organs of the plant: in this way the mineral food of plants is supplied. Every solid found in the plant must have entered in this manner through openings at the extremities of the roots, being, as before stated, too small to allow of the passage of any insoluble particles, however small they may be. But amongst the mineral or ash constituents of plants before enumerated, it will be noticed that several of them are insoluble in water; for instance, phosphate of lime, silica, &c. How, it may be asked, do these substances find their way into the plant? In describing the solvent power of natural water, we remarked that water containing carbonic acid gas in solution is far more active as a solvent for solids than water alone. We mentioned an experiment for showing that the insoluble carbonate of lime, or chalk, is made soluble by this means. In the same manner the more valuable phosphate of lime is to a less extent soluble in water containing car-

bonic acid. The water retained in the substance of the soil, constituting its moisture, is always impregnated with carbonic acid gas, derived from the decaying vegetable matter, and also from the atmosphere. In this condition, water can dissolve the otherwise insoluble combinations of phosphoric acid and other difficultly soluble salts required by plants.

The organic portion of plants consists, as we have seen, of carbon, hydrogen, oxygen, and nitrogen. We will now consider the sources from which plants derive these materials. The greater portion of their bulk—the carbon—is derived from the carbonic acid gas of the air. As before hinted, plants absorb this gas by their leaves from the air, as well as by their roots when dissolved in water. From whichever source derived, on exposure to the sunlight in the organs of the leaf, this gas is decomposed, and separated into free oxygen and carbon. This latter substance is retained, and by the same agency combined with the water also present, and formed into various non-nitrogenous compounds. All these compounds may be regarded as combinations of carbon with water, the oxygen and hydrogen contained in them being generally present in the proportions in which they exist in water. Thus from water plants obtain the hydrogen and oxygen, which with carbon, are the only materials they require to produce all the non-nitrogenous or starchy compounds. This decomposition of carbonic acid, and its subsequent combination with the elements of water in the organs of the leaves of plants, is effected in a mysterious manner by the agency of sunlight. We infer this, because it is known that plants can only perform this operation by daylight, and vigorously only during direct sunshine; but of the manner in which the light acts in breaking up these powerful combinations, we are utterly ignorant; and this matter becomes still more mysterious when we learn that the more complicated albuminous or flesh-forming principles are formed in the same manner by the agency of light. In these com-

pounds, nitrogen and the mineral substances sulphur and phosphorus are present, in addition to the carbon, hydrogen, and oxygen of the simpler heat-giving compounds. The former of these materials are obtained by the plant respectively from ammonia, sulphuric acid, and phosphoric acid; so that each of these powerful mineral combinations has to be decomposed; and their constituents, with those of carbonic acid and water, rearranged in complex groups, that constitute the gluten, casein, and other nitrogenous principles of food. When we learn that these marvellous transformations are effected by the agency of sunlight, we perceive how much we are indebted for our health, happiness, and even existence, to the glorious sunshine.

The nitrogen required by plants for the production of their more valuable albuminous principles, is obtained either from ammonia, supplied by some of the means enumerated while speaking of the atmosphere, or from nitric acid, or some other form of combined nitrogen.

The question naturally occurs to us: Why do not plants obtain the nitrogen they require from the free nitrogen of the atmosphere? It is because plants, notwithstanding the wonderful synthetical power, or the ability of putting together, they possess in their leaves, are unable to overcome the natural disinclination of nitrogen, in a free state, to enter into combination with other bodies. It seems probable that plants do not appropriate the nitrogen from the air, all the nitrogen they require being supplied from ammonia, or some other form of combined nitrogen. Why the supply of nitrogen to plants should be thus restricted, we cannot surmise; we only know that it is so, and may satisfy ourselves that it has been so arranged for a wise purpose.

To some extent we can imagine the different state of things that would exist in the absence of this arrangement. Ammonia, apart from its connection with the albuminous or flesh-forming principles of plants, exercises

a stimulating effect on their entire organism, helping them to digest or appropriate the other kinds of organic and mineral food required for their development. For this purpose, a small quantity of ammonia is provided for the use of plants by nature. But if we supply to plants a larger quantity of ammonia in the shape of manure, we must also supply the other kinds of food, especially the mineral food, at a proportionate rate. In this case the stimulative effect of ammonia resolves itself into a more rapid growth or a higher stage of development, and in the case of some cultivated plants we are enabled by this means to get a larger crop than we should otherwise. If, on the contrary, the mineral food of plants is not present in quantity proportionate to the ammonia supplied, a deformed growth results; the due proportion between the several organs of the plant is upset; the leaves attain a monstrous size at the expense of the root or of the seeds. This effect would probably follow an unlimited supply of ammonia, or what amounts to the same thing, of nitrogen that could be assimilated. We may assume this as a reason why the nitrogen of the air is endowed with properties that unfit it for appropriation in the vegetable economy.

Thus we perceive that plants have been appointed to prepare from simple inorganic compounds, as carbonic acid, ammonia, water, phosphoric acid, &c., the complex materials required to nourish the bodies of animals. These manufactured products, if we may so term them, when received into the animal system, become, on the one hand, the fuel that, by its combustion in the lungs, produces the requisite animal warmth, while others constitute the new material that is to replace the substance of every part of the body worn away and diminished by exercise and exertion.

In the bodies of animals, the reverse of this action prevails. The compounds received in the food commence a series of downward changes, resulting in the reconversion

of their constituents into their normal and simpler combinations. The respiratory principles of the food—the materials above named as the animal fuel—are consumed in the lungs, and are at once returned to the atmosphere as carbonic acid gas and water, while the more complicated flesh-forming materials, after having performed their appointed office in strengthening and invigorating the animal frame, are in their turn expelled from the system in simpler combinations, which, by spontaneous changes, quickly return to the forms they occupied before being appropriated by the plants.

Thus we perceive how plants provide food for animals. Animals do the same for plants; and in either case life is sustained by the operation. Both classes of beings are thus dependent on one another for existence.

CHAPTER VI.

MEANS OF RESTORING THE IMPAIRED FERTILITY OF LAND EXHAUSTED BY CULTIVATED CROPS, AND OF IMPROVING LAND NATURALLY INFERTILE.

Exhaustion of the Soil by Cultivation.

WE are now prepared to inquire into the changes the soil undergoes in ministering to the growth of plants, and shall be able to understand the causes of its becoming exhausted. Plants, as we have seen, derive from the atmosphere and from water but a small number of the materials required for their growth; or, to be more precise, they only obtain from these sources carbon, hydrogen, oxygen, and a little nitrogen; all the mineral substances, and the greater part of the

nitrogen they require in the production of the several organic compounds described in the preceding chapter, must be supplied by the soil. Since every plant thus contains a certain amount of material derived from the soil in which it has grown, it follows that this soil must in all cases sustain a corresponding loss by its growth. Hence, from every cultivated crop the soil sustains a loss proportionate to the abundance and richness of the produce; however fertile or prolific of these materials the soil may be, it must sooner or later show symptoms of exhaustion, or inability to supply a due amount of material for the healthy growth of plants, if a succession of crops are raised upon it, and no equivalent returned to the soil in the shape of manure.

These observations apply only to those crops, or parts of crops, that are carried off the land either directly, in the shape of vegetable produce, or in the shape of live stock. When the whole of a plant is returned to the soil where it has grown, an addition rather than a loss of material is the result, because the soil is enriched by the materials the plant has appropriated from the atmosphere and from water. The extent to which the soil suffers by the various crops raised upon it, will thus be chiefly regulated by the manner these crops are dis-disposed of. For instance, a crop of wheat removes from the soil during its growth a large quantity of nitrogen, phosphoric acid, sulphuric acid, and several other valuable mineral constituents; and although the greater part of this crop, viz. the straw, is returned to the land in the shape of farmyard manure, yet, as the greater part of the more important materials are situated in the grain, which in most cases is sold off the farm, the exhaustive effect of this crop is accounted for. Again a crop of roots, as Swedes, for instance, requires as much material from the soil for its development as the wheat crop; but as this kind of produce is generally consumed on the farm, often on the ground where it has grown, a less amount of

material is lost to the soil, because in either case the greater part of the nitrogen and mineral constituents of the crop is returned to the soil in the shape of manure.

This loss of material, incurred by the soil by the growth of the crops raised upon it, is felt chiefly in inorganic substances, or the mineral food of plants, which constitutes the ash left on burning. The atmospheric food of plants, with the exception of ammonia, exerts no influence upon the exhaustion of the soil, since the amount of carbonic acid, &c., in the atmosphere, practically speaking, is inexhaustible; but as the mineral constituents of plants, such as phosphoric acid, sulphuric acid, potash, &c., are supplied solely by the soil, and the quantities of these materials in a serviceable condition are limited even in the best of soils, it is chiefly by their loss that the fertility of the soil is impaired by cultivation. The amount of nitrogen present in a crop must also be taken into account in considering the extent to which the soil has been weakened. Some persons imagine that ammonia, like carbonic acid, is supplied *ad libitum* to all plants; that the minute quantity of ammonia in the air is sufficient to supply all the nitrogen of plants; and that their ability to absorb this ammonia, and consequently, the amount of nitrogen they receive, is dependent on the quantity of mineral substances at the disposal of the plant. In other words, they imagine that the mineral constituents are the only materials required to be supplied to the plants, and that if these materials are provided in proper quantity, the plants will obtain for themselves from the atmosphere the requisite amount of ammonia to furnish all the nitrogen they require in the development of flesh-forming principles. It seems tolerably certain, however, that the chief part of the nitrogen present in cultivated plants is derived from the soil, to which it has previously been added in the shape of some sort of manure. Thus we may conclude that the nitrogen, as

well as the mineral or inorganic substances contained in a crop, have been supplied at the expense of the soil. In order that we may form an idea of the extent of this exhaustion, and the quantities of the more valuable materials removed from the soil by culture, we annex the following table.

QUANTITIES OF THE MORE ESSENTIAL CONSTITUENTS OF THE SOIL REMOVED FROM IT PER ACRE BY A CROP OF WHEAT

	Wheat (grain) of 25 bushels.
Nitrogen	27·90 lb.
Mineral substance, 26·25 lb., containing,—	
Phosphoric acid	12·07 ,,
Potash	7·86 ,,
Magnesia	3·22 ,,
Lime	·89 ,,
Other less-important mineral substances	1·39 ,,

Rotation of Crops.

Another matter connected with the exhaustion of the soil by culture must now be noticed. It is well known that a soil may be exhausted in reference to one crop, and yet be fertile to a crop of another sort; while it may be incapable of bearing an additional crop of the same kind as that last grown upon it, one of another kind may flourish and come to perfection. This was formerly explained by believing that plants during their growth excreted certain compounds, and that each tribe of plants produced a different kind of excrement, which, although injurious to the plant that produced it, exercised a beneficial influence on some other species of plants. In this way it was explained that several crops of the same kind would not grow successively on the same field, because the excrementitious substances left in the soil by the growth of these crops were present in too large a quantity to admit

of the further healthy growth of the same crop; for the same reason, the ground was believed to be in a favourable condition for the growth of some other family of plants that could appropriate and flourish upon these particular compounds.

This notion, although very popular some time ago, is altogether a theoretical fantasy, as no direct evidence exists even of the formation of these excrementitious matters in the soil by plants, far less of their taking any part in the development of the succeeding crop. The more probable cause of this inability of the soil to produce many successive crops of the same sort is explained by the facts before stated in connection with the composition of the ash of plants. It will be recollected that the ash of a particular tribe of plants always has the same approximate composition, and that while the number of ash constituents of plants seldom varies in different kinds of plants, their amount and relative proportion vary with nearly every variety of plants. Further, it will be remembered that in each kind of plant, some one or two ash constituents predominate, which will obviously be removed from the soil in largest quantity by the growth of the particular kind of plant or crop to which they belong. Hence we can easily understand that a soil which has just suffered a heavy drain upon one or two of its constituents for the development of a particular crop, will be unable to furnish the additional quantity of the same materials requisite for the healthy growth of a second crop of the same kind; but at the same time, its stock of other substances being comparatively undiminished, it is fully capable of responding to the demands of some other crop that is satisfied with a different set of materials. In the same manner several crops of different kinds may successively flourish on land where a second crop of the same kind would utterly fail; but where the same crop, or the same kind of crop, is repeated, even after an interval occupied by intervening crops, the soil will be equally unable to supply it with a

due amount of material, unless it has been replenished by the addition of manure, or unless the interval has been long enough to admit of the conversion of sufficient soluble and wholesome materials, from the insoluble and otherwise useless ones locked up in the fragments of undecomposed rock which most soils contain.

But apart from the character of the materials a crop extracts from the soil during its growth, its place in a series of crops, or in a rotation, is regulated by the capabilities and habits of the plants composing it; it being well known that different kinds of plants are very unlike in their ability to seek their food from the soil and provide for themselves; some plants are helpless, so to speak, and languish for want of food, unless it is placed immediately within their reach. Others, again, are indefatigable and industrious in shifting for themselves even under difficulties, and if food is at all to be had, they will search it out and appropriate it. These latter plants are highly useful for collecting together the small quantities of valuable materials scattered throughout a large bulk of soil. We may distinguish these as industrious plants, since they are noted for sending out roots to great depths and great distances in the soil in search of the materials required for the fabrication of the seeds and other parts of their structure at the surface. To this tribe of plants belong the clovers and grasses; hence the improvement in the surface-soil that may be effected by laying it down in grass, and the advantage that is gained by the introduction of a grass crop in the series of crops of a rotation. Amongst this group of plants, sainfoin is conspicuous, and is highly valued in districts where thin soils overlie porous limestone rocks, as on the Cotswold Hills. This plant possesses in a high degree the power of thrusting its roots to great distances, and collecting and bringing to the surface the small quantities of fertilizing materials these rocks generally contain. The surface-soil is thus enriched, and becomes better adapted for the growth of

those plants above noticed, which, from the rapidity of their development, or for other reasons, are unfitted for searching for their own food. Examples of this latter kind of plants are the turnip, Swede, and other root crops. It is well known that these plants will not flourish unless a copious dose of fertilizing materials is immediately within their reach; and as the substance these plants most require, especially at the early periods of their growth, is phosphoric acid, we can account for the fact that superphosphate of lime (a manure particularly rich in phosphoric acid) is so efficacious in promoting the growth of root crops. For the same reason, the superiority of well-rotted farmyard manure, compared with that in a fresh condition, is mainly due to the larger amount of available phosphoric acid it contains. On these and other circumstances, the rotation proper for a particular kind of soil is founded, and the above remarks are intended to explain a few of the general laws which regulate the order of the crops of a series.

Natural Renovation of Exhausted Soils.

It will now be proper to inquire into the means by which the soil is replenished with the materials removed from it by culture. It is known that a soil wholly or in part exhausted will, if left to itself, in course of time recover its fertility. This effect may be traced to several causes; amongst which the following may be mentioned:—We have seen that several bodies exist in the soil, as oxide of iron, alumina, humus, &c., which possess the power of absorbing and fixing the ammonia from the air. Again, combinations of the same valuable fertilizing material are continually brought down by the rain and stored up in the clay and earth of the soil. The ammonia collected in this manner, although extremely small in quantity, must not be overlooked in considering the natural restoration of the soil. By the growth of

natural herbage, the surface-soil becomes enriched by the accumulation of organic matter derived from water and from the atmosphere, and by the same means any valuable mineral substance existing in the lower regions of the soil will be brought to the surface and distributed through this organic matter. Even during the ordinary systems of cultivation, when the greater part of the produce is carried from the land, the amount of organic matter in the soil in most cases increases, because many plants produce even a larger amount of organic material, in the shape of roots, under the surface, than they do above it, in the shape of leaves, seeds, or other kinds of produce. Hence, when the plants die, all this organic matter is left in the soil, and tends to its improvement, not so much through any direct effect it exerts on the growth of succeeding generations of plants, as by mellowing and loosening the texture of the soil, and by preparing the mineral constituents in a high degree. On the decay of organic matter,—the roots of plants, for instance, in the soil,—all the mineral substances these roots contain are separated in a finely-divided state, and distributed through a porous mass that the roots of living plants can easily penetrate, and upon which they eagerly feed. Another and more important cause of the natural renovation of the fertility of a soil must now be noticed. In describing the mineral constituents of the soil, we have several times had occasion to advert to the fact that the same mineral substances which in a soluble and available form constitute its mineral fertilizing materials, also occur in most soils as stony and insoluble combinations, which take no part in assisting the growth of plants; and it has been remarked that the fertility of a soil depends not so much on the presence of certain compounds, as upon the condition in which these compounds occur. By the unceasing action of the weather, these insoluble and useless compounds are slowly converted into combinations that will admit of conveyance to the organs of plants through the medium of

water; thus, by exposure to the wind, frost, and rain, these soluble fertilizing substances steadily increase and accumulate. To this cause is chiefly to be ascribed the restoration of land when left to itself for a length of time, as in the ancient system of long fallows.

The chief object sought to be attained by the operations of draining, ploughing, exposure to frost, harrowing, cultivating, &c., is the hastening and accelerating the action of natural agents in the last-named process of replenishing the soil.

In many soils, especially the better sorts of clay soils, the quantity of fertilizing materials in this locked-up state is very great—in fact, for generations to come, inexhaustible. Hence the chief business of the cultivator of these soils consists in the employment of the above-mentioned mechanical means for assisting nature in setting free, and rendering available, these hidden treasures; and the application of manures—at least of general manures—becomes a secondary object. But in all soils the above-named mechanical operations constitute an important division of the labour of the farmer, and must in all cases precede the more direct improvement of the soil by the application of manures.

Although the above-mentioned processes may be conveniently considered under the head of "mechanical operations," yet their effects depend to some extent on chemical changes, which we must trace in order to understand their action. Another series of operations, including the application of manures, may be included under the head of "chemical means" of improving the soil. As a preliminary step to entering upon these divisions of our subject, it will be proper to make ourselves acquainted with the distinguishing characters of fertile and barren soils. In order to understand clearly the chemical and mechanical differences between productive and unproductive land, let us first observe the composition of some soils of known fertility.

EXAMPLES OF FERTILE SOILS.

	No. 1. A loamy soil remarkable for producing fine crops of wheat.		No. 2. A rich vegetable mould.
Silica	63·19	..	71·80
Peroxide of iron	4·87	..	6·30
Alumina	14·04	..	9·30
Lime	·83	..	1·01
Magnesia	1·02	..	·20
Potash	2·80		
Soda	1.43	..	·01
Sulphuric acid	·09	..	·17
Phosphoric acid	·24	..	·13
Organic matter	8·55		
Water	2·94	..	10·98
	100·00		100·00

Fertile Soils.

By the above analyses, we learn that in these soils, which may be accepted as standards of fertility, the sand, clay, organic matter, and other more bulky constituents, are so proportioned that neither prevails to an excessive amount. Again, the more valuable mineral constituents, phosphoric acid, sulphuric acid, potash, &c., are present in appreciable quantity, while no substance likely to injure or retard vegetation is present. A fertile soil also possesses many qualities, regarding which chemical analysis gives us no information. The chief of these properties is its texture. A certain looseness, uniformity, or mellowness, extending to a considerable depth from the surface, is requisite to entitle a soil to the appellation of a fertile one. However abundant and complete the chemical constituents of a soil may be, unless these ingredients are intimately mixed and finely divided, it will still require improvement to raise it to its maximum fertility.

Infertile and Barren Soils.

In proportion as the mechanical or chemical qualities of a soil are remote from those above named, so will it be an infertile or a barren one. The sterility of land may be owing to a variety of causes. While many soils are hopelessly infertile, from the obvious reason that they are too thin and poor; others again, equally worthless in practice, present external characters so false that a stranger would be apt to pronounce them to belong to the better class of soils.

We may conveniently consider sterile and deficient soils under three heads. First, those whose sterility is caused by the presence of some substance deleterious to vegetation, or to an excessive quantity of some otherwise useful material; secondly, those in which the absence of necessary food-constituents of plants is the immediate cause of their inferiority; and lastly, soils infertile because their mechanical texture is bad. Amongst the inferior soils belonging to the first of these divisions, are those soils occasionally met with, whose infertility is due to the presence of the noxious sulphate of iron described in a preceding chapter. It is not uncommon for this substance to exist in the subsoil, and not in the surface-soil. In this case, its effects are displayed only upon certain deep-rooted plants, which are found to languish and die as soon as the roots come within the influence of this substance. Peaty and boggy soils belong to this class, as in these cases the excessive quantity of vegetable remains is the immediate cause of infertility. Coupled with this defect, and in most cases the primary cause of it, is the presence of stagnant water. This of itself constitutes a source of infertility. Hence wet, undrained, cold soils must also be included in this division.

To the second group of infertile soils belong those that have been exhausted by injudicious cultivation: these may still retain a fine mechanical texture, their

chemical health only being impaired. Soils that are deficient in substance, as those that are too thin and shallow, must also be considered as belonging to this division. Soils of the third kind are those whose mechanical texture unfits them for supporting the healthy growth of plants. They may be too close, heavy, and retentive, as in clay soils, or too loose and porous, as in sandy soils. Soils of the former description frequently occur, containing in abundance all the materials required for the vigorous growth of every sort of crop, and require only mechanical improvement to convert them into soils of superior character. Such soils may be called crude soils.

EXAMPLES OF BARREN SOILS.

	No. 1. A barren sandy soil.		No. 2. A peaty sterile soil.
Silica and sand	96·00	..	7·96
Alumina	·50	..	·63
Oxide of iron	2·00	..	·12
Lime	·01	..	·55
Magnesia	trace	..	·08
Potash	—	..	·01
Soda	—		
Phosphoric acid	—	..	·02
Sulphuric acid	—	..	·19
Chlorine	—	..	—
Organic matter	1·49	..	90·44
	100·00		100·00

We will now proceed to consider the means at our command for removing or ameliorating the above-named general causes of infertility. Some of these means will also constitute a necessary department in the cultivation of all soils.

Mechanical Means of Improving the Land.—Draining.

Of these mechanical operations, draining is undoubtedly the most important, since, apart from the fact of an

excess of water being a common source of infertility, an efficient means of drainage may be regarded as an indispensable condition in all cultivated soils; and this in many instances can only be attained by artificial drainage. In some soils, the natural drainage is too active, and constitutes a serious defect, as in sandy, porous soils. In most cases, however, the reverse of this state of things exists, and nothing can be done with the soil until an artificial system of drainage is established. This is especially the case in clay soils, which, as we all know, are exceedingly retentive of moisture. In these, and to a less extent in soils of other characters, the water that falls in the shape of rain, or that drains from higher ground, accumulates and stagnates, and seriously interferes with the growth of plants, unless an effective outlet is provided. When no outlet for the water exists, a morass or bog is formed, and the soil becomes entirely unproductive. When the means of escape for the water are defective, a corresponding reduction of fertility ensues; and although the surface-soil may not apparently be suffering from an excess of moisture, it often happens that the subsoil is permanently soaked with stagnant water, which greatly retards the healthy growth of plants. Thus, like many other good things, water, which, as we have seen, is so essential in every stage of the development of plants, becomes, when present in excessive quantity, altogether injurious. The evil effects of too much water in the soil may to some extent be explained as follows.

The soil in a healthy condition consists of a layer of porous substance, full of cavities and pores, through which the atmospheric air and the gases produced by the decay of organic matter continually circulate. The air is indispensable in the soil to enable the functions of growth to proceed and new supplies of fertilizing material to be prepared. If, as in the case of undrained land, these cavities and pores of the soil are filled with water instead

of air, it is clear none of these necessary changes can proceed. Further, in the presence of stagnant water, all sorts of unnatural compounds are formed in the soil, which more or less interfere with the growth of plants and the health of animals. The proper circulation of the air through a soil is in a measure dependent on the means of exit that exist for water. When a shower of rain falls on properly-drained ground, the rain in penetrating into the soil drives out the inclosed air, to occupy its place; but on the cessation of the rain, as the water continues to sink into and through the soil, it is followed by a new supply of fresh air, which in its turn acts upon the vegetable and mineral substances of the soil; and thus the process of decay and consequent production of fertilizing material proceeds with renewed vigour.

Moreover, the clay and other substances of the soil are capable of extracting from rain-water the small quantities of fertilizing materials which, as already noticed, it generally contains. When a shower of rain sinks through the soil, most of the substances the rain-water holds in solution are retained and appropriated by the roots of plants; but when the soil is already saturated with water, as in undrained land, no passage, or only a limited one, through the soil can be found by the rain; it therefore merely runs off the surface, and these valuable constituents are wasted.

Wet undrained soils are also sometimes called "cold" soils. This is a very proper name for them, since soils that contain an undue quantity of water are actually colder than they would otherwise be. This is explained by the facts noticed in a previous chapter in describing the properties of steam. It will be remembered that steam, whether natural or artificial, always contains a large quantity of heat, and that the evaporation of water, or its conversion into steam, is always attended by a loss of heat. Thus the heat of the sun shining upon wet ground is wasted by the evaporation of a portion of

the water, which, in becoming steam, absorbs the heat that would otherwise be retained in the soil, and the soil being deprived of a proper amount of heat, vegetation is retarded. Moreover, in the steam thus given off from stagnant water soaking in earth, all kinds of poisonous vapours are present; the miasma of warm climates, and the milder forms of it in temperate ones, that give rise to agues and fevers so common in countries where drainage is altogether neglected, are emanations of this kind. Any one may satisfy himself of the production of noxious vapours from stagnant water under these circumstances by mixing any earth with water in an open vessel, and allowing the mixture to stand for three or four weeks: during this period the mixture will have acquired an abominable odour.

Thus by the process of draining, the soil is rendered more porous, open, and looser; all its cavities and interstices, formerly occupied by stagnant water, are now filled with sweet air, busily employed in promoting a healthy decay of the vegetable and mineral substances that the soil contains, and converting them into wholesome food for plants. The earth is thus mellowed, enriched, and in every way better suited for the purposes of agriculture. By draining, the soil is also made deeper; a greater depth of earth will be penetrated by the roots of the plants growing upon it, and an additional increase of produce on this account may be looked for.

Since by draining, the land is made warmer, and the crops growing upon it hastened in their growth and brought sooner to perfection, the draining of a district produces a change tantamount to an improvement of climate—it becomes drier, warmer, and more wholesome and healthy to its inhabitants.

Another important effect of draining is in hastening the drying of soils after wet weather. As every farmer knows, the land must be in a proper state of dryness before any kind of work upon it can be attempted; and however

inconvenient or expensive a delay may be, this condition of the soil must be waited for. Anxiety from this cause is often felt in wet autumns, when prolonged rainy weather interferes with the sowing of the wheat crop.

Land that is properly drained is, of course, much less subject to remain in this wet, unmanageable condition than undrained or imperfectly-drained land; and as in the former case the proper condition of dryness during the intervals of wet weather is sooner reached, an opportunity will often be afforded for carrying on the necessary operations of the season, while land of the same kind, but undrained, remains in a state wholly unfit to be touched, and some other course of procedure than the one intended has to be adopted, even though at inconvenience and loss.

A further effect of draining must now be noticed; viz., the assistance it affords to all manuring materials. Manures, of whatever sort, can be more economically applied on drained than on undrained land; in other words, the same quantity of manure will go farther, or produce better effects, on moderately dry ground than on that which is wet and undrained. We can easily understand the reason of this: it is only what we should expect on recollecting that most kinds of manure, like organic matters and other substances provided by nature in the soil, require to be more or less altered by the atmosphere before they can exert any useful effect; and as the quantity of air present in an undrained soil is very limited, it is not surprising that manures should require a longer time to act, and produce less effect, than in better-constituted soil. Moreover, we are now aware, that most fertilizing materials act upon plants through the medium of water; the water, or moisture of the ground, dissolves small quantities of the mineral substances and conveys them to the roots of the plant; but in order that water may perform the office properly, it must circulate or move through the soil in different directions. During rain, the water falling on the surface will gradually pass downwards

through the soil. Again, during hot, fine weather, the evaporation from the moist surface will impart an upward tendency to the moisture in the soil; but in whichever direction the moisture moves through the soil, it will carry with it small quantities of the manuring materials it has dissolved from the fragments of those substances it has met with at different points of its course; and being everywhere intercepted by the roots of plants, it yields to these delicate organs as much of the materials it has gathered as they are inclined to make use of. But in undrained land, where the water of the soil is more or less stagnant, or incapable of circulation, the fragments of manuring substances become inclosed in a layer of saturated material, and all those particles not immediately adjacent to the roots of the plants take no part in contributing to the growth of the crop, and for the time being are useless.

From these observations we may infer that draining is the first and most important means at our disposal for the improvement of all descriptions of land in which an undue proportion of water prevails. It merits this distinction not only on account of the numerous beneficial changes it effects in the texture of the soil, but also because it is almost indispensable as a preliminary step to the employment of other more direct fertilizing agents. All the resources of scientific agriculture will be useless, unless a proper amount only of water is maintained in the soil, and the removal of every quantity beyond this is provided for. This, as before remarked, can generally only be secured by artificial drainage.

Ploughing.

The mechanical operations of ploughing, subsoiling, trenching, &c., can only be employed to greatest advantage after a proper drainage has been secured.

Ploughing, besides the more immediate effect of breaking up and loosening the soil, exerts a secondary action,

by exposing to the action of the weather a greater surface of the soil than would otherwise be the case. This effect of ploughing is strikingly displayed in winter fallows. The action of frost in reducing the soil to a state of division far beyond anything we can produce by artificial means, is well known; and since on the flat surface of a soil the effects of frost would be but small, in consequence of the short distance to which frost usually penetrates, a much greater advantage may be gained from this effect of frost by ploughing up the ground in autumn, and in this condition leaving it exposed to the action of the weather. By this plan masses of earth and clay will be exposed on all sides to the frost, and become frozen through their bulk. In this process, the moisture they contain, on being converted into ice, expands, and thus forces and holds apart every particle of earth contained in the mass. On the return of warmer weather, the ice again becomes fluid, returns to its original bulk, and the separated particles of earth now crumble down to a beautifully light porous mass, which, in a high degree, promotes the absorption of ammonia and other fertilizing constituents of the atmosphere.

Deep Ploughing, Subsoiling, Trenching, &c.

The principal effect of ploughing is to break up and loosen the soil, so that the air, which, as we have seen, is so necessary to the healthy condition of the soil, may freely penetrate through it in every direction. The roots of plants will generally only descend so far from the surface as this loosening by the plough extends. The depth to which the plough can be used will, of course, in a great measure, be regulated by the natural depth of the soil; but in many cases, no reason exists why this natural depth should not be extended, and the soil deepened by encroaching on the subsoil. On some kinds of land great improvement has been effected by this means.

To this end deep ploughing and subsoil ploughing are employed. By these operations the deeper regions of the soil are loosened, and will now admit of penetration by the roots of certain deep-rooted plants; at the same time the drainage of the surface-soil is still further promoted, and its wholesome porosity maintained. The most useful effect of these operations consists in furnishing the soil with a new store of fertilizing materials, which the lower portions of many soils contain, either belonging to them naturally, or that have been washed into them by the continued action of rain and other agents, which constantly tend to bury all materials added to the surface-soil. The recovery of these buried treasures is still further assisted by the gradual admixture of the subsoil with the surface-soil, as in trenching and allied operations.

The striking effects often seen to follow the adoption of trenching and deep ploughing in increasing the produce of districts where the use of these operations had previously been unknown, may be traced principally to this cause. The valuable material removed from the surface-soil during many generations, is again brought into use, and acts with renewed vigour in promoting the growth of plants. Moreover, the deeper layers of soil, that have hitherto remained undisturbed, often contain valuable mineral constituents, which, when mellowed by exposure to the atmosphere, greatly add to the fertility and productiveness of the surface-soil.

After ploughing, we naturally arrive at the allied operations of harrowing, cultivating, rolling, cleaning, &c. By these auxiliary means the necessary looseness and well-mixed condition of the soil is more completely attained: by the same operations the ground is cleaned, or freed from those inveterate enemies to the farmer—the weeds, or those plants that are too ready to grow. In all cases it is advisable to burn the weeds collected in this way during the cleaning of land. By this means they

are effectually prevented from again taking root and distributing their seeds, while at the same time their ashes become valuable additions to the fertilizing materials of the soil. The more completely these operations of pulverizing, mixing, and cleaning the soil are carried out, the finer will be the growth of the following crop, and the smaller the quantity of manure it will require to raise this crop to perfection. As before stated, all artificial manures go further on a soil that is well cultivated than on one that is full of coarse lumps, and is carelessly mixed and cleaned. We can easily imagine that this should be the case. A given bulk of earth in a soil that is well prepared will admit of a greater number of roots and fibres penetrating through its substance than when the same space is occupied by coarse unbroken lumps, as in a carelessly-prepared soil. In the former case every portion of the soil adjacent to the plants of a crop will be intermingled with roots, which will make use of every fragment of manuring material within their reach; and thus every portion of the manure added will take part in supplying the growing crop: whereas, in the latter case, a great part of the manure applied gets beyond the reach of the roots, and in this isolated position is for the time being useless. Moreover, the substances supplied in the shape of manure to certain crops, as for instance phosphatic manures for root crops, are required by the plants *during the early stages of their growth;* and unless these substances are within the reach of the tender roots at this early period, much of the good effect expected from the manure will not be forthcoming. Thus, although even in an imperfectly-prepared soil the manure applied may ultimately be reached by the roots of the plants, yet at this more advanced period of their growth it will be of much less use to them than if earlier supplied. This fact is so well known by manure-makers, that some of our largest manufacturers of superphosphate also supply their customers with the best implements at

reduced rates, in order that the maximum effect of their manure may be displayed on the crop to which it is applied.

Intermediate in character between the mechanical and chemical means of improving the land, are some important operations, which must now be briefly considered: these are, mixing, paring and burning, liming, marling, &c. While, on the one hand, the texture of the soil is materially altered by the bulky nature of the materials concerned in these operations, an equally important effect is often produced by the chemical action of some of these materials.

Mixing of Soils.

Much improvement may often be effected in the texture of a soil by adding to it those kinds of earth it seems to be most deficient in; for instance, a heavy clay soil will obviously be improved by the addition of sand or any other loose and porous material. Again, sandy soils require only clay to overcome their chief failing; viz., their want of retentiveness; while, on thin, scanty soils, the addition of earthy matter of almost any description will effect improvement by adding to their depth and substance. In most cases, economical considerations present insurmountable obstacles to improvement of soils by these means; at the same time it must be admitted, that in many situations, where the requisite materials are at hand, immense improvement might be effected, and at an outlay for which the increased produce of the land may reasonably be expected to pay a good interest. Beds of sand are often found underlying the stratum of clay on which the soil rests. Again, deposits of clay are often accessible from districts where sandy soils prevail: in cases of this sort, the spare labour of horses and men may be profitably expended in thus adding useful material to the defective soil. The addition of clay to a soil deficient in this material not only im-

proves its mechanical condition, but greatly adds to its fertility, in virtue of the numerous useful qualities before mentioned as belonging to clay.

Paring and Burning.

An important operation, which possesses in a high degree claims that entitle it to be considered both as a mechanical and chemical means of improving the soil, must now be described; we allude to the operation of paring and burning, as well as the burning of clay by other means, for use in agriculture. These operations are especially valuable in heavy, clay soils, where every practicable means of increasing the looseness and porosity of the soil is to be eagerly sought for. At the same time they can be employed with advantage on lighter soils, since, in virtue of the chemical action of the burned materials, an amount of fertilizing substance, equal to that imported by a good dressing of manure, is often added to the soil by the operation of paring and burning.

The operations of paring and burning are not always connected: it is often profitable to burn clay by some sort of cheap artificial fuel; and as in all cases the burned clay is the more effective material, we will first inquire into the changes clay and earth undergo in the process of burning. We must again call attention to the fact that all soils, more especially clay soils, contain a great deal of fertilizing materials in a crude, undecomposed state, —a form that cannot be made use of by plants. It has also been stated that by the slow action of the rain, frost, and other atmospherical phenomena, these insoluble substances are slowly rendered soluble and converted into a form that can be made use of by plants. The same changes can be effected more rapidly by fire. As in the case of organic matters, the same changes that take place by long exposure to the air at ordinary temperatures during the process of decay, are produced almost instantaneously at

a higher temperature, or, in common language, by fire; so, in a less degree, with these mineral constituents of the soil, fire is capable of performing in a short time what is slowly effected by long exposure to the action of the weather. When clay is burned at a very high temperature in a furnace or kiln, it partially melts, and becomes a vitreous hard mass, which on cooling retains any form that may have been given to it before burning, and is almost imperishable by the weather. On this property of clay depends its application in the art of pottery, or the manufacture of useful domestic articles of crockery-ware. But when clay is burned at a lower temperature, as when burned in heaps with coal-dust or vegetable matter, its physical properties are altered to a less extent, and it becomes a porous friable substance, that easily crumbles to powder on exposure to the air. This burned clay differs from unburned, in having lost its plasticity, or that property of adhering and sticking together when wet. In this burned condition it remains in a powdery state, even when soaked with water, and in this respect partakes of the characters of sand. On this mechanical property depends its value as a means of lightening and imparting porosity to heavy, clay soils. But in its chemical qualities it also differs widely either from unburned clay or that which has been fused at a high temperature. In the latter conditions but very little of the constituents of clay are soluble in water; whereas, in clay that has been properly burned at a low temperature, many of its constituents are rendered soluble in water, and others are so changed in constitution that by exposure to the air they readily become soluble, and at once capable of furnishing food for plants. It is chiefly on this chemical property of burned clay that its usefulness is based.

In the operation of paring and burning, other chemical changes are produced besides those above stated relating to clay. A quantity of organic matter is burned: this

consists of vegetable remains, stems and roots of plants, with considerable quantities of animal matter in the shape of the larvæ and bodies of insects, &c. It may at first sight seem a wasteful process thus to burn and dissipate in the air what by decay would yield organic food to plants; but the fact is, most of the organic matter destroyed in this process is unfit for any useful purpose. In certain kinds of soils the organic matter accumulates too rapidly, and attains an objectionable proportion in the soil: in these cases, burning supplies us with the best means of getting rid of it. Again, the operation of paring and burning is generally resorted to on foul pastures, or land full of roots and weeds, which often resist all other means of destruction. In all these cases, the destruction of organic matter cannot be lamented; and even when the organic matter is of a less-objectionable kind, its sacrifice for the more valuable products of burning may often be advantageous. In the case of weeds or inferior grasses, much benefit will result to the soil from their destruction by fire; since these plants, like their cultivated brethren, remove from the soil useful mineral substances. The soil is thus impoverished to supply these useless plants. When burned, however, all the mineral substances they have consumed are recovered, and returned to the soil in a condition that can at once be appropriated by cultivated plants. Thus the ash obtained by paring and burning consists of a mixture of burned clay and earth with the mineral constituents of the vegetable matter used in the process, and together constitutes a valuable manure, especially for root crops.

Liming.

The use of lime is justly esteemed as one of the best means we possess for improving certain kinds of soils. On many soils the addition of lime is followed by increased fertility, and in numerous cases the improvement

effected in this manner is so striking, that we cannot wonder at liming being at present ranked amongst the standard operations of agriculture.

We have remarked on a former occasion, that lime is required for the growth of all kinds of cultivated plants, and, consequently, is an indispensable constituent of all cultivated soils. But while lime is invariably present in soils that admit of cultivation, the quantity of lime naturally contained in them is often very small, and especially too small for the vigorous growth of certain crops. Hence the addition of lime to soils of this description must obviously increase their fertility. It is on soils of this kind that the most striking effects of lime are displayed, especially when, as is not unfrequently the case, a soil contains in abundance all the materials required for the growth of plants, with the exception of lime. In these cases, the addition of lime is all that is necessary to transform a comparatively barren soil into one of superior quality. To a less extent, the use of lime on ordinary soils is generally attended by good effects ; and even on lime soils, that contain a large proportion of calcareous material, the use of lime of some other sort, or from some other district, is frequently beneficial. Hence we find that lime acts in the soil in several capacities.

It not only acts as a direct manure, by increasing the supply of a material necessary for the growth of nearly all plants, but it supplies us with one of the best means of altering the condition of substances already present in the soil, either by destroying or modifying substances that are objectionable and noxious, or by the conversion of indifferent bodies into useful fertilizing materials. For instance, a soil whose fertility is impaired by an excessive quantity of vegetable matter, as a peaty or boggy soil, may be relieved of this encumbrance by a copious dose of quick-lime. We have already described the properties of lime, and it will be remembered that lime, like all alkaline or caustic substances, possesses the property of rotting

and destroying organic matter of every sort. Hence, on its addition to soils of this description, it quickly diminishes the quantity of insoluble vegetable remains. In speaking of the properties of humus, and other organic matters of the soil, we alluded to the well-known fact that vegetable remains, under peculiar circumstances, refuse to decay, and accumulate to an injurious extent. This kind of vegetable matter, popularly known as "sour humus," is generally found in undrained, or but imperfectly drained land. To remove this sour humus, lime is generally employed, which, by acting upon the insoluble vegetable matter, hastens its decay, and is said to "sweeten" the land; as by decay these materials furnish carbonic acid and other useful feeding materials for plants. The lime thus converts a noxious ingredient into a source of fertility. Again, in the case of soils that are infested with insects, a dose of lime is the least troublesome and most effective remedy.

One of the most useful effects of lime seems to depend on the changes it effects in the mineral constituents of the soil, as in the last-described operation of burning, the decomposition of the various minerals of the soil is accelerated, and silica, potash, and other useful food-constituents of plants set free.

In considering the agricultural value of lime, we must not forget its mechanical effect on the soil. When applied in large quantities to clay lands, it opens and loosens the dense masses of clay, and imparts a certain amount of porosity and mellowness; and by so doing opens the way to further improvement, by exposing a larger extent of surface to the action of the atmosphere.

Thus we perceive the changes that can be brought about in the soil by the addition of lime are numerous and important, and in some measure account for the high value attached by some persons to this substance as a manure.

The effects of lime in the soil, as above briefly

enumerated, are most actively exhibited by lime in a caustic or freshly-burned state; but also in a less degree by lime in other conditions. Whenever practicable, it is advisable to apply the lime in the state of hydrate, or as slaked lime. We have already described the chemical properties of lime, and the changes it undergoes by burning and slaking. It will be remembered that one of the effects of these operations is to reduce the lime to a fine state of division, so that, apart from the superior chemical effects of slaked lime, by using it in this condition we gain a further advantage, from its peculiar mechanical form, which admits of intimate admixture with the soil, and thus secures the fullest effect that lime is capable of imparting. In using lime in this condition, the lime is generally brought to the field in a caustic or hot state, and put up in small heaps, loosely covered with earth. In the course of two or three weeks the lime is completely slaked and falls to powder, which can now be easily spread over the land.

The quantity of lime applied to the land in this manner will, of course, vary with the purpose it is intended to serve. If the lime is employed for a special object, as, for instance, to remove the excess of organic matter from old pastures when broken up, a copious dose of lime will be necessary; but where the soil has become deficient in lime, and an additional quantity is added, to act as a direct manure, a much smaller quantity suffices. Much difference of opinion exists amongst practical men as to the best system of liming the land. While some persons recommend a large dose at long intervals, other persons think it better to use a smaller quantity more frequently. Theoretically, we should think that, provided no reasons exist to the contrary, small doses at short periods would be the better system for obtaining the fullest effect of lime; since it is well known that everything applied to the land exhibits a tendency to sink in the ground, and bury itself beyond

the reach of the plants. The following table exhibits the quantities of lime applied in different districts :—

QUANTITY OF LIME APPLIED PER IMPERIAL ACRE IN DIFFERENT DISTRICTS.

	Bushels.	Years.	Bushels in a Year.	When applied.
Roxburgh	200	every 19	or 10½	To the fallows
Ayr (Kyle)........	40	,, 5	,, 8	Ditto, ditto or lea
Carse of Stirling....	50	,, 6	,, 9	ditto
South Durham	90	,, 12	,, 8½	ditto
Worcester	70	,, 6 or 8	,, 10	Before grasses & tares

It is found in practice that different sorts of lime act very differently when applied to the soil ; in other words, the lime produced from one kind of limestone will be found to produce superior effects to that made of some other sort of limestone rock, although, perhaps, this latter contains quite as much real lime as the former. Hence it is clear that the increased fertility following the application of lime to the land is not always entirely due to the real lime it contains. Moreover, the fact above referred to—viz., that on certain soils resting on limestone formations, and containing abundance of lime, the addition of lime of some other sort is often highly beneficial—compels us to seek for some other explanation than that afforded by the known effects of real or pure lime.

We must bear in mind that the lime produced from any natural source is not, chemically speaking, pure lime, but a mixture of pure lime with certain foreign matters in greater or less abundance. These foreign substances are found to materially influence the effects of a particular kind of lime, and often account for its superior or inferior quality. Of these impurities of limestones the more common are sand, oxide of iron and alumina, magnesia, &c., which to some extent affect the value of the lime made from it ; but the agricultural value of limestone is chiefly regulated by other materials, generally present in

much smaller quantities; indeed, in quantities so small, that until comparatively lately they were altogether overlooked. Amongst these we may mention phosphoric acid, sulphuric acid, the alkalies potash and soda, &c. As these substances are all valuable fertilizing materials, we can no longer wonder that a limestone containing small yet appreciable quantities of them should produce a lime that exercises a better effect on the soil than a purer kind of lime free of these materials; and it must be remembered, that although the quantity of these more precious substances is small compared with the bulk of lime employed, yet, as large quantities of lime are often added to the land, the absolute quantity of the above-named fertilizing materials will be considerable, and often equal to that contained in a dressing of farmyard manure. We annex some analyses of two or three well-known varieties of agricultural limestones.

COMPOSITION OF LIMESTONES USED FOR AGRICULTURAL PURPOSES.

	Great Oolite or Bath-stone.	Cornbrash.	Mountain Limestone.
Carbonate of lime	95·34	89·19	96·35
Magnesia	·73	·77	2·28
Oxide of iron and alumina	1·42	2·98	·67
Phosphoric acid	·12	·18	—
Equal to bone earth	(·26)	(·36)	—
Sulphate of lime or gypsum	·20	·24	—
Soluble silica	1·01	1·23	·70
Insoluble sand, &c.	1·18	5·41	
	100·00	100·00	100·00

In using lime as a manure, it must not be supposed that other manures can therefore be dispensed with. Lime is a special manure, and performs in the soil an office of its own sufficiently important to entitle it to a high place amongst manures; at the same time, it ought never to be used in place of farmyard manure. It is quite true that

on certain fertile soils the addition of lime without any other manure is all that is necessary to insure abundant crops; and from this fact we might naturally infer, as many farmers have inferred, that lime is a substitute for other manures. But this is a grievous error. Lime, by its stimulating effect on the soil, will for a time replace manure, by exciting the soil to supply sufficient material for the growth of several successive crops; but this supply is effected at the expense of the strength of the soil; it is drawing upon its capital, and must sooner or later feel the effects of this undue exhaustion.

On the other hand, the opinion entertained by some farmers of the exhaustive effects of lime in all cases, and that therefore it ought not to be employed, is equally erroneous. The fact is, no ill effects are likely to follow the use of lime, provided other kinds of manure are supplied in proportion: it is from neglect of this principle that most of the failures experienced in the use of lime are to be attributed. Lime ought never to be applied at the same time with other manures; it is advisable to put off the application of other manures as long as possible to land that has been recently limed. This precaution is the more necessary in the case of manures that contain combinations of ammonia; since, as we have seen, lime liberates ammonia with the greatest ease from all its combinations. Hence the simultaneous application of lime and farmyard manure would probably be attended with a considerable loss of fertilizing material. No fear of loss need be entertained from this property of lime after it has been exposed in the soil for two or three months, as by this time all the caustic lime will have become carbonate of lime, and have lost its more active properties.

Marl, Chalk, Shell-sand, &c.

It is not always expedient nor practicable to apply lime to the soil in a caustic or burned state: in these cases other forms of lime must be resorted to; as marl, chalk,

shell-sand, and even limestone rock. All these materials act in a similar manner as burned lime, but in a less vigorous degree, and at a much slower rate. Moreover, these substances are found to vary in composition, and consequently in their agricultural value, even more than limestones. Marls especially are found of all degrees of fitness for use as manures, some of them being particularly rich in fertilizing materials. The mechanical form and condition of marls greatly add to their value as means of improving the soil; but as the number and varieties of calcareous mixtures, locally called marls, are very great, it is quite impossible for us to enter into any details respecting them. The value of all these materials, apart from depending on the lime they contain, will generally depend on the proportion of phosphoric acid, the alkalies, and other essential mineral-food constituents of plants; and, in conclusion, we may remark, that their agricultural value can in most cases be ascertained by a complete and rigorous chemical analysis.

COMPOSITION OF A FEW CALCAREOUS MATERIALS USED IN AGRICULTURE.

	Chalk.		A marl of the West of England.	Shell Sand from Cornwall.
	Lower.	Upper.		
Clay and insoluble matter	2·04	1·46	22·80	12·12
Carbonate of lime	96·51	97·20	73·80	80·08
Oxide of iron and alumina	·55	1·05	·78	1·68
Magnesia	·25	·06	·82	3·17
Phosphoric acid	·07	·04	· 4	·23
Sulphuric acid	·31	—	1·54	·93
Potash	·08	·17	trace	·31
Soda	·19	·02		
	100·00	100·00	100·00	100·00

Chemical Means of Improving the Land.

Of the operations hitherto described, the greater number are in most cases employed as preliminary steps to the more direct improvement of the soil by the application of manures; and as the action of the various manures is essentially chemical, although a mechanical effect may in some cases be exerted in a minor degree, they may conveniently be considered under the above title, which also includes all those operations by which some essential change is effected in the composition of the soil; some of these operations we are already acquainted with, as, for instance, liming, paring and burning, &c. There remains for our consideration a most important division of our subject; viz.—

The Application of Manures.

The application of manures consists for the most part of putting back into the soil an equivalent for what has been taken from it in the shape of cultivated produce. But this is not all we can do by means of manures: we can also add more material, and other materials, than the soil already possesses; and thus, by altering its constitution, endow it with new qualities and capabilities, so as greatly to increase its productiveness. If a soil is naturally deficient of some material required in the development of a particular crop, this crop cannot be successfully cultivated; but if we add the requisite material, the soil will now be capable of producing the desired crop. It often happens that soils possessing most of the characters of fertility, are yet defective, from an insufficient quantity of one or two essential constituents; by adding these constituents, and thus increasing their proportion in the soil, the defect is at once overcome, and the quality of the land greatly improved.

Amongst the soils usually met with, few of them can

be called complete soils, or are capable of producing several kinds of crops with equal degrees of vigour and abundance; in most cases, the soil is naturally best fitted for the growth of a particular family of plants, which is often indicated by the wild plants that flourish upon it. This unequal capability of soils is dependent on the proportions of their constituents; and, generally speaking, the species of plants that most delight to grow on a particular kind of soil contain mineral constituents whose relative abundance corresponds with that of the constituents of the soil in which they are found to flourish, and which we may therefore fairly conclude is most favourable to their growth.

For this reason, each kind of soil commonly met with favours the growth of a particular crop, or is better adapted for raising one kind of produce than another. For instance, clay soils will produce abundant crops of wheat, while they are scarcely capable of yielding a good crop of turnips; turnips, again, will flourish in lighter soils, that are unsuited for wheat; while lime soils are particularly favourable to the growth of leguminous plants; as clover, pease, &c. A complete soil, on the contrary, is one that will produce with almost equal luxuriance every kind of cultivated crop. In a soil of this kind the constituents are so proportioned that neither of them abounds to so great an extent as to interfere with the vigorous growth of any kind of plant, while, at the same time, every material required by each cultivated plant is present in sufficient quantity to admit of its luxuriant growth. A soil of this description may be called a perfect one; and were all soils of this character, the farmer might raise his corn and rear his cattle with as much ease as some persons ignorant of agricultural pursuits seem to imagine. But, as most of us know, soils of this kind are seldom met with in practice; the characters of the soils usually cultivated by farmers, are in most cases remote from these qualities, and require

careful management to raise from them sufficient produce to pay expenses of cultivation. It is, however, the object of an advanced system of agriculture to alter and improve these defective soils, to extend their capabilities, and increase their productiveness. This can only be accomplished by perseverance in the employment of suitable mechanical means of improvement, and in the judicious application of manures.

In theory, we may convert any defective soil into a fertile and complete one by the addition, in proper quantities, of those materials it is deficient in; and, on a small scale, we may carry out this theory in practice. For instance, we may make a garden on any kind of soil, and, by the addition of proper materials, soon prepare a fertile mould, capable of producing in luxuriance every kind of plant of whose growth the climate will permit. But in practice on a large scale, as on the land of our farms, the case is very different. The alteration we can effect in the character of the land in this manner is limited by considerations of £. *s. d.*; the question in these cases is, not what can be done, but what can be done to pay. The extent of soil in our fields being so vast, tons of material being required to produce the least appreciable change in the composition of the soil, alteration to the same extent as in the case above referred to becomes wholly impracticable. At the same time we must remember that, by a prolonged course of skilful cultivation, immense improvement may be effected, and has been effected, in several parts of this country.

Since the term Manure, in the sense usually understood, includes a great number of different substances, most dissimilar in their properties and the effects they exercise on the land, it will be proper to adopt some system of classification, in considering this most important division of Agricultural Chemistry. Farmyard manure, superphosphate of lime, soot, lime, marl, &c., are all called manures; yet the effects which these substances severally

exercise on the soil are widely different,—the only property they possess in common being, that they are all more or less useful in promoting the growth of plants. We will consider these materials under two heads :—1st. Those substances provided by Nature as manures. These will chiefly consist of the solid and fluid excrements of animals, or a mixture of these with vegetable substances, as used in farmyard manure. 2nd. All those materials known as artificial manures; as bone-dust, superphosphate of lime, guano, nitrate of soda, &c. Amongst these we shall also include refuse material; as wool-refuse, gas-liquor, sugar-refuse, &c. Manures may further be divided into two classes,—1st, those called general manures, which add to the general fertility of the land, as farmyard dung, and other mixtures; and 2nd, those manures which act only on particular crops, or are used to perform some special purpose in the soil. Hence they are called special manures; as bone-dust, gypsum, nitrate of soda, sulphate of ammonia, &c.

It will be well to begin with farmyard manure, since this material unquestionably holds the first rank amongst all kinds of manures.

Farmyard Manure.

From the earliest periods of the history of agriculture to the present time, the material most employed for imparting fertility to the land, has been the mixture of the solid and liquid excrements of domestic animals and various kinds of litter, known as "muck" or "dung;" and even at the present time, when the art of tilling the soil has attained a high degree of excellence, and involves the use of numerous artificial manures,—of whose powers exaggerated notions are frequently entertained by uninitiated persons,—the old-fashioned and bulky material —dung still occupies the first place amongst manures. This must necessarily be the case, because farmyard manure is the natural source, and the most economical

one, on which the farmer can rely for sustaining the fertility of his land.

In speaking of the products of vegetable growth, we remarked that the food of animals consists of mixtures of the vegetable principles called woody fibre, starch, sugar, gluten, and other compounds, prepared by plants for the nourishment of animals; and that when these mixtures are received into the bodies of animals, some of the above compounds they contain are consumed in the lungs to produce the requisite animal heat, and are hence called "heat-giving" principles; while a lesser and choicer portion is disposed of in building up and renewing the muscles and sinews exhausted by exercise and labour. Hence, these compounds are included under the general term of "flesh-forming" materials. When the compounds of this latter kind have performed their appointed office, —have taken their share in supporting the functions of animal life,—they are in their turn dismissed from the position they had occupied in the animal frame, and now seek to return to the condition they occupied before being manufactured by the plant. In other words, the flesh-forming materials of the food having become part of the flesh of the animal, are again removed (in consequence of the unceasing process of decay and renewal common to all grades of animal life), and finally are expelled from the system in the solid and liquid excrements. These substances consist of the same ultimate constituents as the food from which they have been formed, but differently arranged, or, generally speaking, merely grouped together in simpler combinations or smaller parties. The solid excrements also contain the undigested portions of the food with other solids, that can be removed from the system by no other means. So far from this matter being repulsive, as imagined by some fastidious persons, it displays to us, when viewed philosophically, the beautiful circle of operations necessary to the existence of animal and vegetable life.

Thus we may conclude that all the materials of the food consumed by an animal are again returned either to the atmosphere through its lungs, in the breath, or, with the exception of a small quantity carried off by the skin, to the earth, in the shape of the solid and fluid excrements.

The urine of animals is by far the more valuable portion of their excrements. It contains the greater portion of the nitrogen originally present in their food. It will be remembered that the nourishing power of food is in a great measure dependent on the amount of nitrogen it contains. This is because the nitrogen is the more essential constituent of the nourishing principles of food. The same standard can be applied to a large class of manuring substances. In these cases the value of the manure, or the food of the plant, is also dependent on the amount of nitrogen it contains; because, by decaying in the soil, all this nitrogen will be converted into ammonia —a substance, it will be remembered, that is one of the most valuable feeding materials for plants. For this reason the urine of animals is a most valuable manuring substance, far more valuable than the solid excrements, which contain much less nitrogen. On the same principle that we are too often regardless of the pernicious substances we may inhale with our breath, because they are invisible, so, in a less degree, we think less of the fluid manure at our disposal, because it presents so much less to our sight than the more bulky, but far less valuable, solid dung. Every care should be taken by the farmer to preserve the urine of his cattle from waste, since, in addition to the valuable properties it possesses, in virtue of the nitrogen it contains, other materials, highly valuable as fertilizing agents, are present. The nitrogen present in urine exists in several different combinations, called by chemists urea, uric acid, hippuric acid, &c.; but these compounds are all so far alike, that by spontaneous decay all the nitrogen they contain separates in the form of

ammonia, which escapes into the air, unless measures be taken to prevent its doing so. It is from this source that the ammonia always present in the atmosphere of stables, as noticed in a former chapter, is derived. The urine of the horses that is not absorbed by the litter, is quickly decomposed, and evolves free ammonia, or, to speak more correctly, carbonate of ammonia. Of course, the ammonia, liberated in this manner, is at the expense of the manure produced in stables; and although a considerable proportion of this ammonia may be recovered by the means noticed in speaking of the properties of ammonia, yet, however efficient these means may be, a portion of it will always escape and be lost. This is one, amongst other reasons, why the manure produced by feeding cattle in boxes is superior to that prepared in any other way. By this system the urine is completely retained in the litter, and little of it wasted either by drainage or separation into volatile ammonia. As we shall presently learn, the ammonia produced by the decomposition of urine does not escape when this decomposition proceeds in the substance of a mass of solid manure and litter, as in a dung-heap. It is only when exposed alone in its fluid condition that its fermentation is attended by any considerable loss of ammonia. In addition to the compounds of nitrogen above described, which all yield by decomposition the valuable ammonia, other compounds of mineral origin, and nearly as valuable, are also present in urine. The properties of phosphorus and its combinations, as fertilizing materials, have already been noticed; and it was remarked, that the value of these compounds is the greater when they occur in a form that is soluble in water. In urine a large proportion of these soluble compounds of phosphorus exists. Hence, on this account alone, it should be highly prized as a manuring material. Again, potash, with other mineral substances of more or less fertilizing value, are also present in considerable proportion. In urine these solids are dissolved

in a large quantity of water, and for this reason cannot be recognized by our unaided senses. In order that an idea may be formed of the composition of urine, we subjoin an analysis of the urine of the more common domestic animals.

APPROXIMATE COMPOSITION OF THE URINE OF THE

	Horse.	Cow.	Sheep.	Pig.
Water	890	920	865	975
Organic matter, urea, uric acid, &c.	80	60	99	15
Containing nitrogen, capable of yielding of ammonia	(16·)	(9·)	(17·)	(4·)
Inorganic matter, salts of potash, soda, &c.	30	20	36	10
Containing phosphoric acid	(1·20)	(·7)	(·48)	(1·25)
	1000	1000	1000	1000

By the above analysis it will be seen that the composition of the urine of different animals varies exceedingly; at the same time, it must be understood that the composition of the urine of animals of the same kind is by no means constant, being subject to variation from a number of causes; as for instance, from age, sex, the quality and quantity of food consumed, condition of the animals, &c.: the above results may, however, be accepted as fair approximations to the average composition of the urine of each of the species of animals named.

The solid excrements consist of those portions of the food unfit for assimilation; consisting for the most part of woody fibre, as well as of other insoluble materials of the food that can only be removed from the system through this channel. The composition of the solid excrements of different kinds of animals varies to a still greater extent than that of the urine above described; moreover, the mechanical form of these substances materially influences their agricultural value, as it is on this circum-

stance that the facility with which they undergo decay chiefly depends, and consequently that regulates their fitness for particular purposes. The average composition of the solid excrements of our domestic animals may be thus stated :—

APPROXIMATE COMPOSITION OF THE SOLID EXCREMENTS OF THE

	Horse.	Cow.	Sheep.	Pig.
Water	760	840	580	800
Organic matter, woody portions of food, and other insoluble matter	210	136	360	170
Containing nitrogen, capable of yielding of ammonia	(6·10)	(3·6)	(9·02)	(·73)
Mineral substances, consisting of insoluble salts of food	30	25	60	30
Containing phosphoric acid	(3·48)	(2·25)	(6·2)	(4·5)
	1000	1000	1000	1000

Of these materials, in a fresh condition, but a small proportion is soluble in water ; for this reason they are less valuable than the liquid urine. Again, they contain less nitrogen that can yield ammonia, and the more valuable mineral fertilizing elements are not so abundant as in urine. By exposure to the air and moisture, these substances also enter into putrefaction, and liberate the nitrogen they contain as ammonia ; at the same time, these insoluble constituents are rendered soluble, and consequently more valuable as manuring agents ;—hence these substances become more valuable after fermentation or incipient decay, provided this fermentation takes place in a manner that prevents the escape of the ammonia liberated during the process. We also find in the solid excrements substances that are absent, or nearly so, in the urine,—as for instance, lime, magnesia, silica, &c. ; and as these substances, like the more valuable phosphoric

acid, ammonia, &c., must be regarded as indispensable for the healthy growth of plants, we perceive that the solid and liquid excrements of animals are best adapted and evidently intended to be used together as a manure—the one substance containing what is deficient in the other, while together they contain every material required for the growth of plants. When both of these substances are present, distributed through a porous mass of vegetable material, as straw or litter, they constitute the mixture known as farmyard manure,—the most complete, most valuable, and only perfect manure. Whatever assistance the farmer may derive from the use of artificial manures, he should rely only on his farmyard manure for supporting the fertility of his land; since this substance *only* can return to the land *all* the materials removed from it by cultivation. From the number of its constituents, the naturally favourable arrangement of these constituents, and the peculiar mechanical condition in which they occur, and its low price, we are justified in considering farmyard manure as the most valuable of all fertilizing materials, and superior to any artificial mixture that we can obtain at the same cost. Persons unacquainted with Agricultural Chemistry or with practical farming, are apt to form extravagant notions of the power of artificial manures; they seem to think that by the use of a small quantity of odorless, cleanly, dry powder, the more bulky and, to them, offensive farmyard manure may be dispensed with. It need scarcely be said that such is not the case;—no amount of artificial manures, however skilfully mixed and prepared, can ever imitate farmyard manure, or be used in its place. At the same time, it must be recollected that in the hands of skilful farmers, artificial manures are valuable, nay, at the present time, indispensable additions to farmyard manure for the growth of certain crops; but in all cases, as before observed, these substances will be of minor consideration, and the chief resource on which the farmer must depend for the growth of his crops and the rearing

of his cattle will be farmyard manure, or, to call it by its old English name, dung.

In the production and management of this important material, great errors are often made, and corresponding losses incurred by farmers. Many men thoroughly practical in other respects, do not understand the management of farmyard manure, and have yet something to learn in this department of agriculture. That this matter should not be properly understood, is not surprising when we learn that the management of dung depends upon certain chemical principles only recently made out. Until quite lately, little was known concerning the changes farmyard manure undergoes during fermentation, and still less of the relative merits of the different modes in use for the production of this important material.

This matter is now thoroughly explained, and the chemical changes involved in the operations clearly made out; while the extent to which these changes are regulated in different systems of management has been rigorously determined.

This important investigation has been lately completed by Dr. Voelcker, and the results have been published by him in a recent volume of the *Journal of the Royal Agricultural Society*. This investigation, carried out by means of practical experiments on a large scale, as well as by the more delicate operations of refined chemical analysis, will no doubt confer great benefit on the agricultural community, and cannot fail to be duly appreciated by every one who is interested in the progress of agriculture.

In the carrying out of this investigation in the laboratory of the Royal Agricultural College, I enjoy the honour of having contributed a humble part, and am therefore in a position to speak confidently and from personal experience on the facts adduced in the following description of the changes farmyard manure undergoes by keeping; and it is hoped that this description may not be unworthy

of the attention of practical men, who may, we think, gather from it hints that will be of service to them in the treatment of farmyard manure.

Farmyard manure, consisting of the solid and liquid excrements of horses, cows, and pigs, mixed with the straw used as litter, is found to be a mixture of most uncertain composition. This absence of uniformity arises from the fact that this material is exposed to variation from many sources, the more prominent of which may be thus enumerated :—1. The quantity and quality of the food supplied to the animals that produce it. 2. The relative number of animals of one species that take part in its production. 3. The age of these animals. 4. Their breed and condition. 5. The quantity and quality of straw used in the manufacture of the manure. On account of these circumstances scarcely two samples of farmyard manure can be found alike, yet on any one farm where a particular system of feeding and management is followed, the manure produced will be tolerably uniform; and all samples of farmyard manure, wherever and however produced, are so far alike that the following general remarks will apply with equal force to all. An average sample of fresh farmyard manure, or long dung, was found to consist of,—

GENERAL COMPOSITION OF FRESH LONG DUNG (COMPOSED OF HORSE, COW, AND PIG DUNG).

	In Natural State.
Water	66·17
Soluble organic matter *	2·48
Soluble inorganic matter	1·54
Insoluble organic matter †	25·76
Insoluble inorganic matter	4·05
	100·00

* Containing nitrogen	·149
Equal to ammonia	·181
† Containing nitrogen	·494
Equal to ammonia	·599
Total per-centage of nitrogen	·643
Equal to ammonia	·780

Or, to be more precise, in 100lb. of the material were found,—

COMPOSITION OF FRESH FARMYARD MANURE (COMPOSED OF HORSE, PIG, AND COW DUNG, ABOUT FOURTEEN DAYS OLD).

Detailed Composition of Manure in Natural State.

Water		66·17
Soluble organic matter *		2·48
Soluble inorganic matter (ash) :—		
Soluble silica	·237	
Phosphate of lime	·299	
Lime	·066	
Magnesia	·011	
Potash	·573	
Soda	·051	
Chloride of sodium	·030	
Sulphuric acid	·055	
Carbonic acid and loss	·218	
		1·54
Insoluble organic matter †		25·76
Insoluble inorganic matter (ash) :—		
Soluble silica	·967	
Insoluble silica	·561	
Oxide of iron, alumina, with phosphates	·596	
Containing phosphoric acid	(·178)	
Equal to bone earth	(·386)	
Lime	1·120	
Magnesia	·143	
Potash	·099	
Soda	·019	
Sulphuric acid	·061	
Carbonic acid and loss	·484	
		4·05
		100·00

* Containing nitrogen	·149
Equal to ammonia	·181
† Containing nitrogen	·494
Equal to ammonia	·599
Whole manure contains ammonia in free state	·034
„ „ in form of salts	·088

By an examination of the foregoing analysis we learn that fresh farmyard manure contains all the materials required for the growth of plants. Organic matter is present to supply carbonic acid and ammonia, also mineral substances of every description that are in any way connected with vegetation; phosphoric acid, potash, lime, soda, silica, all are present. It is chiefly for this reason that farmyard manure merits the title of the only complete manure. Yet by other qualities its claims to this distinction are still further supported, the principal of these being its peculiar mechanical form, the porous, bulky condition in which it usually occurs. As this quality is more prominent in fresh farmyard manure, recent dung is generally to be preferred for application to heavy clay land, where every means of loosening the soil is to be eagerly sought for. When applied in a fresh condition in Autumn to soils of this description, it greatly assists the action of frost in mellowing and loosening their mechanical texture.

By the above analysis we also perceive that of the numerous substances which enter into the composition of fresh farmyard manure, but few are soluble in water, the greater number being insoluble in water. We also notice that in many instances the same substance is present both in a soluble and insoluble condition.

As we are already aware, a substance must become soluble in water before it can be received into the organization of plants. In this manner we can account for the well-known fact that fresh farmyard manure seldom exerts any immediate effect in promoting the growth of plants. As we shall presently see, the principal transformation effected in dung by fermentation in masses or on decay in the soil, consists in rendering these insoluble matters soluble, in which condition only they are capable of exerting any beneficial action on plants.

We now state the composition of well-rotted manure,

or short dung. An average sample, about six months old, was found to consist of:—

COMPOSITION OF ROTTEN DUNG.

Detailed Composition of Manure in a Natural State.

Water		75·42
Soluble organic matter *		3·71
Soluble inorganic matter (ash):—		
Soluble silica	·254	
Phosphate of lime	·382	
Lime	·117	
Magnesia	·047	
Potash	·446	
Soda	·023	
Chloride of sodium	·037	
Sulphuric acid	·058	
Carbonic acid and loss	·106	
		1·47
Insoluble organic matter †		12·82
Insoluble inorganic matter (ash):—		
Soluble silica	1·424	
Insoluble silica	1·010	
Oxides of iron and alumina, with phosphates	·947	
Containing phosphoric acid ..	(·274)	
Equal to bone earth	(·573)	
Lime	1·667	
Magnesia	·091	
Potash	·045	
Soda	·038	
Sulphuric acid	·063	
Carbonic acid and loss	1·295	
		6·58
		100·00

* Containing nitrogen	·297
Equal to ammonia	·360
† Containing nitrogen	·309
Equal to ammonia	·375
Whole manure contains ammonia in free state	·046
" " form of salts	·057

By this analysis we perceive that the constituents of well-rotted dung are the same as those of fresh; the difference between them being chiefly determined by the condition in which these constituents exist. The most striking difference is in the larger proportion of soluble materials present in rotten dung, notwithstanding the large quantity of water it generally contains. On further comparing the composition of the two kinds of manure, we notice that this increased solubility is especially apparent in the more valuable nitrogenous compounds, or those materials that yield by decay ammonia. Again, a greater proportion of the precious phosphate of lime, or bone material, is present in a soluble state than in fresh dung. On acquaintance with these facts we can no longer wonder that well-rotted dung should be more immediately effective in promoting the growth of plants than in a fresh condition, as we now perceive it contains a much larger quantity of both organic and mineral food of plants, in a state that can at once be appropriated by the growing plants. The dense and more compact condition of well-rotted manure also favours the rapid supply of its fertilizing constituents to the roots of plants; since a larger quantity of it will be within the reach of the roots of plants at one period. For this reason well-rotted dung is always to be preferred for application to root crops. On the whole we may conclude that well-rotted farmyard manure is more valuable than the same weight of fresh. The next question to consider is, how much of a given weight of fresh manure is left after undergoing fermentation and conversion into rotten dung; in other words, how much, and of what kind of material, is lost during the process of fermentation.

It has before been stated, that when animal or vegetable substances are removed from the influence of organized life, they spontaneously ferment, putrefy, or decay. In these natural processes, the materials composing the organic matter undergo a series of changes, which

terminate in their reconversion to the simple forms in which they originally existed, before they became part of the organized compounds.

We have instanced decay and putrefaction as operations analogous to combustion or the destruction of organic matter by fire; in either case the ultimate products are the same, and the heat that accompanies either process is in direct proportion to the rapidity of chemical action. We may therefore regard the operations of fermentation and decay as processes of slow combustion; the only real difference between them and combustion being one of time: the ultimate products in each case are the same. It has also been remarked that the readiness with which organic substances enter into decay is generally regulated by the number of materials of which they are composed. The more intricate their composition, the sooner they show symptoms of decay. These preliminary remarks are necessary in order that we may understand the changes that take place during the fermentation of farmyard manure.

In the mixture of animal and vegetable compounds that we call farmyard manure, circumstances are generally favourable for inducing the early stages of decay commonly called fermentation, or more properly putrefaction. The complex materials of the urine are diffused through a moist, porous mass of substances exposing a large surface to the inclosed air. It is these compounds belonging to the urine that first enter into putrefaction, and, in virtue of their property before adverted to, of exciting a tendency to change in other more permanent compounds, fermentation soon becomes general through the mass.

This fermentation is the more active the warmer the weather, heat being in every case conducive to the alteration of organic matter: a certain amount of moisture is also necessary to the healthy fermentation of dung. If the manure is too dry, the operation is retarded; while,

by an excessive quantity of water, as when manure is allowed to soak in wet weather in yards, the process is entirely stopped. Under favourable circumstances, the fermentation of manure will steadily proceed until it assumes the compact form and dark colour of well-rotted or short dung.

During this process the manure is found to shrink much in bulk and lose a great deal of its weight. The questions naturally occur to us—of what does this loss consist? and what becomes of it? In describing the destruction of organic matters by fire, it has been said that the greater portion of their substance passes off in the shape of carbonic acid gas and water; while the smaller quantity of nitrogen they contain is liberated in the shape of ammonia; and the ash or the mineral substances are left behind. The same remarks apply to the slower process of decay, the early stages of which we call fermentation or putrefaction.

During the fermentation of manure, a portion of the woody fibre of the straw and other non-nitrogenous compounds, are converted into carbonic acid and water, which fly off, while the larger portion of these materials is changed into the black porous substance *humus*, before described as forming a part of the soil. This substance, or, to speak more correctly, mixture of substances, is always formed when organic matters suffer destruction by decay; aud, as we shall presently learn, it performs an important part in the fermentation of farmyard manure. The dark colour of well-rotted dung is due to the presence of these compounds.

A great portion of the nitrogen contained in the nitrogenous compounds of the fresh manure is liberated in the form of ammonia,—the volatile gas so often referred to as one of the most useful of fertilizing materials. One would naturally imagine that this substance, being volatile, would escape from the dung-heap during fermentation. A portion of it does escape, as may be proved by

a simple experiment; * but the quantity of ammonia that escapes in this manner is exceedingly minute. The outcry often raised about the wasteful loss of ammonia by the fermentation of farmyard manure, and the necessity of employing chemical means for avoiding this loss, is based upon the supposition that *all* the ammonia liberated from the nitrogenous compounds of the manure escapes into the atmosphere; but this is not the case. When fermentation is properly conducted, and the heap left as much as possible to itself, the ammonia liberated in the interior of the heap does *not* escape; or at least the quantity that does so—and that is sufficient to indicate the presence of ammonia by the test above named—is so small as to be altogether unworthy of notice in practice. However advisable it may be to employ chemical means for fixing the free ammonia given off by manure under particular circumstances, as in stables and in some other cases, nothing of the kind is requisite during the fermentation of dung-heaps. Nature provides means of fixing the ammonia simultaneously with its production. It is only in the hottest parts of the interior of the mass that ammonia is separated in a volatile state; and this, in its passage towards the surface through the exterior and cooler portion of the heap, is intercepted and retained by the humic acid and other allied compounds above noticed, which, as we have seen, possess in a high degree the power of fixing ammonia. And as a further provision against loss of ammonia, another substance having a great attraction for it, called gypsum, is also formed from the sulphur present in the manure.

The mineral constituents of the manure undergo no

* Made by holding in the steam escaping from a fermenting dung-heap, a strip of moistened red test-paper. This paper is dyed with a colouring matter which becomes red or blue according as it is exposed to the action of acids and alkalies:—the fact of the red colour being turned to blue in this case, proves the presence of ammonia, which is a strong alkali.

less important changes during the process of fermentation. The chief of these changes consists in their being rendered more soluble in water; and hence the fertilizing value is increased. The two more essential mineral constituents of plants are sulphur and phosphorus; since one or both of these substances are required in the production of the flesh-forming principles of food: these two bodies are also present in the fresh excrements of animals, combined in certain organic compounds. By putrefaction these compounds are broken up; and the sulphur and phosphorus, being liberated, again form new combinations; amongst which are two gases called respectively phosphuretted and sulphuretted hydrogen. These gases, together with other more intricate volatile compounds, fly off and give rise to the peculiar smell of fermenting dung. Only a minute portion of the sulphur and phosphorus escapes in this way; the larger portion of them is found in the rotted dung, in the shape of phosphoric and sulphuric acids.

During the fermentation of dung, the fluid portion sinks to the bottom of the mass, and drains away, while if, as is generally the case, the heap is exposed to the weather, every shower of rain that falls adds to this loss, by washing out of the manure much soluble matter; and since, by rotting, the manure becomes richer in these soluble materials, it is clear that unless some measures are taken to preserve these drainings, great loss is incurred from this source.

The above description of the changes fermented manure undergoes by keeping, applies to the early stages of decay known as fermentation, or more properly as putrefaction. When these periods are past, and the manure has become fully ripe, or has attained its maximum value, it should at once be made use of, and added to the land; since by longer keeping it becomes deteriorated, by undergoing further changes, and soon becomes weakened and unable to retain all its fertilizing materials.

From the preceding description of the fermentation of farmyard manure, we gather the following facts :—

1. That the loss of substance sustained by farmyard manure during fermentation is caused by some of its constituents escaping into the air in the shape of gases, and by other fluid portions that drain away.

2. Those gases that escape into the atmosphere are comparatively of little value, since in most cases the plants to which the manure is afterwards applied will suffer but little deprivation from the absence of these volatile matters, which consist for the most part merely of water and carbonic acid gas.

3. On the contrary, that portion lost by drainage is the most valuable portion of the manure, as it consists of ammonia, potash, phosphoric acid, and every other material valuable to cultivated plants.

4. That ammonia, in any appreciable quantity, is not lost by escaping into the air, as is often supposed; but that it is retained in the heap in combination with certain organic acids, as humic acid, and other carbonaceous substances of the same kind, which are formed from the vegetable matter of the manure. That while this natural provision effectually prevents loss of ammonia by evaporation, no protection is afforded against loss by drainage; since many of these compounds are soluble in water.

5. That these natural means of fixing ammonia can only act when the fermentation proceeds undisturbed, so that the ammonia liberated in the interior and hotter portions of the mass may pass into the cooler and outer layers, where it can be retained; for this reason, the turning of manure should be as much as possible avoided.

6. When the active fermentation of manure has ceased, no loss of ammonia will now follow exposure by turning; in fact, it may be spread over the land without fear of loss from this cause.

Finally, manure, when properly rotted, should be at once used, since its value diminishes by further keeping.

From a consideration of the foregoing statements, we may arrive at the following general deductions.

The use of farmyard manure in a fresh condition, or as well-rotted dung, will depend on the means at our disposal, and the kind of land to which we intend applying it. In the case of the soil being one of a heavy character, in which additional porosity and looseness will be advantageous, the best thing we can do when circumstances permit, is to apply the fresh dung at once to the land; and if we cannot at once plough it in, spread it over the surface. In doing this, no fears need be entertained of loss of fertilizing materials; on the contrary, by this means security from loss is almost insured, since in this disseminated state fermentation cannot proceed, and everything separated by drainage is received into the soil, where it is securely preserved until required by the following crops. In the application of dung to the land, the absorbent property of clay must be remembered. In speaking of the constituents of the soil, we mentioned as one of the properties of clay, its power of retaining saline and other manuring substances, and preventing their removal from the soil by heavy rains. If our soil contains any moderate quantity of clay, we may avail ourselves of this property, and spread manure over our fields, and leave it in this state until we can conveniently plough it in, feeling assured that anything washed out of the manure by rain or dew will be stored up in the soil as safely as if the manure itself were buried. While in this condition, no ammonia or any other volatile matter of any value will escape.

By at once adding manure in a fresh condition to our land, and afterwards ploughing it in, we secure all the vegetable matter which by fermentation is volatilized as carbonic acid gas. As before remarked, this loss in most cases is not worth caring about, because soils that have been under cultivation for any length of time generally contain enough organic matter of this description; but on new ground,—land containing but little humus, it may

in some cases be advisable to avoid the loss of this vegetable matter. This can but be done by ploughing into the land the fresh or long dung.

If the soil is not of a character to benefit by the mechanical effect of long dung,—or in cases where fresh dung is unfitted for the crop we intend to raise, as, for instance, a root crop,—it becomes necessary to ferment the manure before applying it to the land. This operation is best conducted in well-constructed waterproof pits, provided with a sound tank for receiving the drainage. With this tank a pump should be connected, so that by suitable means the fluid drainings may from time to time be diffused throughout the fermenting manure. The question whether the manure-pit should be roofed in or not will depend on the character of the manure produced on the farm. If, as is the case in certain districts, an excessive quantity of straw has to be disposed of by conversion into manure, the manure will often be too dry to admit of a proper fermentation: hence exposure to rain will be beneficial. On the contrary, when litter is scarce, and the manure is naturally wet, all additional moisture from rain is to be carefully avoided. The most complete method of keeping manure seems to be in covered pits communicating with a tank, whence the requisite moisture can be supplied from the fluid drainings, and applied to the manure as required. In the construction of all receptacles of manure, especial care should be taken that proper waterproof linings be used, to prevent loss by drainage.

It has been shown that the loss incurred during the fermentation of manure is chiefly from drainage; for this reason manure-heaps should never be set up in situations where the drainings from them cannot be recovered. This fact cannot be too well remembered by practical men, who so frequently neglect taking any measures to avoid this source of loss, which is far more considerable than one would naturally suppose. No object is more common in agricultural districts, than a manure-heap standing by the

side of a lane, or on a piece of waste ground, where no provision whatever exists for collecting the drainings. The rich black drainings trickle away to a neighbouring ditch or pool, and often raise a fine crop of weeds, whose seeds being carried to the surrounding fields, produce an uninvited crop, for the destruction of which a further loss in labour has to be endured. These drainings that flow from dung-heaps may, without exaggeration, be called the essence of the manure. After heavy rains, the quantity of valuable material wasted in this way is very great, and for this reason too much care cannot be taken to preserve the fluid portion of manure; and if no means exist for keeping manure in pits, it should at once be carted to the field where it is intended to be used, and whenever practicable, at once spread over the land instead of setting it up in a heap at one corner of the field; but where this is unavoidable, the surrounding earth should be heaped up, to absorb as much as possible of the drainings. The quantity of fertilizing materials that sink into the ground around and under a dung-heap, is often pointed out to us by the increased luxuriance of the plants growing on the spot where, even some years before, a dung-heap stood.

When manure is spread over the land, there is no necessity of immediately ploughing it in; indeed, it is highly probable that, by not doing so, the soil is more evenly manured; the soluble fertilizing materials contained in the manure are washed out by the rain, and distributed more uniformly throughout the substance of the soil, and, as before remarked, on soils that contain a fair proportion of clay, no anxiety need be felt for loss of manuring substances by this course of procedure. On the contrary, in sandy, light, or hungry soils, that possess very little retentive power, the manure should be added in a well-rotted condition, and not be applied sooner than is absolutely necessary; since every shower of rain will carry off a portion of the manure intended for the crop. On soils of this description, the best system of manuring seems to be

the application of small but frequent doses. As before noticed, it is chiefly for this reason that the system of liquid manuring succeeds best in light lands.

With regard to the different systems of manufacturing manure by keeping the animals in boxes, stables, or yards, the first-named plan is undoubtedly the best for the production of manure, whatever objections of other kinds it may be open to. In box-feeding, the urine of the animals is better preserved and more intimately mixed with the solid excrements and litter, the whole being well incorporated and consolidated by the treading of the animal; moreover, the mixture undergoes a gentle fermentation throughout its bulk, which greatly adds to its future value. In sheds and stables a considerable portion of the urine is often wasted from the absence of effective drainage; and even where good drainage exists, and the urine preserved, the manure produced in this way is generally inferior to that made in boxes.

The system of making manure in open yards is most wasteful and objectionable, particularly in cases where no drainage exists for collecting the fluid portions of the manure, or only that provided by nature. It is not uncommon to see the drainage of a yard received by the pool that supplies the cattle with water, or rather the putrid liquid that had much better be called liquid manure.

This system of making manure is objectionable in every respect, perhaps chiefly on account of the facility it affords for the deteriorating influence of rain, wind, and snow. By these agents the manure produced is gradually extracted of all valuable fertilizing materials it may contain, and soon becomes next to worthless. In an experiment made on a large scale in connection with the investigation before referred to, for ascertaining the relative merits of the different systems of preserving manure, it was found that manure spread in the usual manner over open yards exposed to the weather, loses an enormous proportion of

its useful materials; and, as might be expected, the loss it sustains is the greater in those materials most useful to plants.* After twelve months' exposure, it was found to contain but a trace of material that could furnish ammonia, and proportionately minute quantities of every other useful substance. Without entering into any details of this very interesting experiment, we may remark, that after twelve months' exposure, two-thirds of the substance of the manure had been wasted, while the remaining portion was next to worthless, consisting for the most part of the woody matter of the straw used as litter.

Artificial Manures.

In order that we may clearly understand the nature of artificial manures, their several properties, and in what they differ from farmyard manure, let us for a moment depreciate farmyard manure, and point out its defects.

We find that, in so far as the chemical value of this mixture is concerned, it depends chiefly on the presence of three or four essential materials, and that these materials are distributed through a large bulk of comparatively useless substance; and is rendered additionally cumbrous by the large quantity of water it contains: in round numbers, two-thirds of the weight of farmyard manure are water. On learning these facts, the question naturally occurs to us, why cannot we prepare these essential materials in a separate or concentrated form? For instance, we learn that the most valuable constituent of farmyard manure is ammonia; but to get one pound of this substance, we must take 137 lb. of well-rotted farmyard manure. Again, phosphate of lime is a valuable constituent of dung; but 100 lb. of dung contain only about

* A large quantity of manure was kept in a yard, in the manner usually followed in this system of feeding, and was examined at regular intervals.

1 lb. of this substance. Why cannot ammonia or phosphate of lime at once be taken and added to the soil? In reply to these questions, it may be said that there is no reason whatever why we should not do this, if we can do it economically; in fact, this is what we endeavour to do by making use of artificial manures. These substances may be regarded as the essential constituents of farmyard manure in a concentrated form. At the same time, it must be recollected that the less essential materials of farmyard manure, as soluble silica, magnesia, lime, &c., although less precious than the rarer substances above named, are yet necessary for the healthy growth of plants; and even if we were so disposed, it is doubtful whether any artificial mixture we could prepare in imitation of farmyard manure would act so well as this substance in the soil; since the peculiar organic combinations of its constituents and the mechanical form of farmyard manure would be deficient.

It was in seeking replies to the above very natural questions, that the value of artificial manuring substances was discovered. As soon as scientific men had clearly made out what materials are required by plants for their growth, and in tracing the sources of these materials had pointed out which were the more valuable constituents of manure, the notion of adding these substances artificially was readily conceived. The practice of adding artificial manures was, however, to some extent adopted before the principles on which they acted were understood. It was found, in certain cases, that the addition of some one substance to the land produced a better effect than could be obtained from farmyard manure. A striking example of the power of a special manure, and the unconscious adoption of a scientific principle, may be instanced in the pastures of certain parts of Cheshire. As is well known, these meadows, originally remarkable for their fertility, and the richness of the cheese produced in this district, by continued pasturing became impaired, and began to show

symptoms of exhaustion which could not be removed by the manure usually applied. It was found that the addition of bones to the soil produced the desired effect; the grass regained its accustomed sweetness and cheese-producing qualities. This restoration of the weakened pasture by the use of bones can now be easily explained, and will be adverted to in describing the composition of bone-dust.

In the same way, other substances have been found in practice to benefit certain crops, in a manner that could not be satisfactorily explained some years ago.

The more common difference between artificial manures and farmyard manure is the smaller number of constituents the former substances contain. While farmyard manure is composed, as we have seen, of a large number of materials,—in fact, it contains all the fertilizing elements required in the growth of plants,—artificial manures, on the contrary, contain but a few—often but one or two—of these elements.

A further difference may be thus stated: in farmyard manure the rarer and more precious fertilizing substances are scarce, and form but a small proportion of its bulk and weight, whereas, artificial manures (that is, of the better sort) consist, for the greater part, of some or all of these more essential substances.

The two more important classes of artificial manures are called respectively ammoniacal, or nitrogenous manures, and phosphatic manures. The first class consists of those in which ammonia, or what is nearly the same thing, combined nitrogen, is the prevailing constituent. To this class belong guano, nitrate of soda, sulphate of ammonia, soot, gas liquor, and animal refuse manures. By means of these manures we can supply to plants any quantity of ammonia that seems desirable: they are chiefly used as top dressings, for urging the growth of corn crops in spring; although, in smaller quantities, useful for other purposes. The second class—the phosphatic

manures—are those in which phosphoric acid is the chief ingredient, although other substances in less quantity are generally also present. Of these manures superphosphate is the principal: bone-dust and certain sorts of guano also belong to this group.

Since superphosphate is perhaps the most important of all phosphatic manures, we shall now do well to direct our attention to this substance, and, as a necessary preliminary step, to consider the composition of bones and other phosphatic materials; of which, as most of our readers are aware, superphosphate is manufactured.

Bone-dust.—The bones of animals differ from all other organic products by the large amount of mineral or earthy matter they contain. Organic matter of animal origin, like that of vegetable origin, generally contains but a small proportion of mineral substances, seldom more than two or three per cent. of its weight; but in bones we find a much greater proportion of earthy matter. In fact, about two-thirds of the weight of bones consists of mineral salts; the remainder consists of animal matter, chiefly of the same description as that composing skin, gristle, &c., called gelatine, with varying quantities of fat. When bones are burned, this animal matter burns away; the fat burns with flame like other non-nitrogenized compounds, while the gelatine is decomposed and yields the nitrogen it contains in the form of ammonia. The mineral portion, or ash, left behind when all the combustible matter is burned away, consists chiefly of phosphoric acid combined with lime and magnesia, in a compound called bone-earth, with smaller quantities of carbonate of lime and in still smaller quantities, the alkalies potash and soda.

The value of bones as a manure chiefly depends on the gelatine and the phosphoric acid they contain. The former substance, in common with all animal matters except fat, yields, by decay in the soil, ammonia; while the phosphoric acid combined with lime and magnesia,

under the same treatment, is slowly dissolved by the moisture of the soil, and conveyed into the organism of the plant, there to perform the important functions allotted to it.

The bone-dust supplied for agricultural purposes consists of the bones of oxen, sheep, horses, &c., crushed to fragments, according to the size of which they are called half-inch or quarter-inch bones; and some of still smaller fragments. These bones have generally been deprived of their fat, and often of a considerable portion of their gelatine; and further, they always contain impurities in the shape of sand and earthy matters, and often materials of vegetable origin. For these reasons, commercial bone-dust is a mixture of very uncertain composition, and consequently its agricultural value differs to a corresponding degree. The following analyses will convey a good idea of the composition of bone-dust of two or three qualities: the first and second samples consist of bone-dust of good quality, the small quantity of impurities being accidental:—

GENERAL COMPOSITION OF COMMERCIAL BONES.

	Half-inch Bones.	Quarter-inch Bones.	Boiled Bones.
Moisture	12·67	13·97	8·06
Inorganic matter, gelatine, fats, &c.	30·12	33·39	25·45
Phosphate of lime and magnesia (bone-earth)	48·14	44·95	60·48
Carbonate of lime	6·99	5·36	3·25
Alkaline salts, chiefly common salt	1·91	1·72	·63
Sand and mineral matter	·17	·62	2·33
	100·00	100·00	100·00

Apart from the intrinsic value of various qualities of bone-dust, as depending on the amount of phosphoric acid and nitrogen they contain, much of their practical value

depends on the treatment they have received at the hands of the dealers and collectors.

In this country, where economy of material is in some trades (not including farming) carried to a degree of refinement undreamt of by uninitiated persons, bones in their raw state are too valuable to be at once delivered over to the farmer. They contain materials that can be more profitably disposed of. As the agricultural value of bone-dust thus depends on the previous treatment it has undergone, it will be well to enumerate the more common modes of treatment pursued towards commercial bones. 1. By boiling the bones in open coppers, the fat is extracted: this is removed by skimming, and sold for soap-making, &c. The bones, thus deprived of fat, are either at once supplied to farmers or are dealt with as in processes Nos. 2 and 3. Most of the bones supplied for agricultural purposes have been thus deprived of fat, and in this condition are superior to natural bones, because the fat that these always contain greatly retards their action in the soil. It is found that a piece of fresh bone buried under the surface of the soil undergoes little change, and for a length of time refuses to decay. This is explained by the fact that the fatty matter it contains diffused through its substance effectually excludes the air and moisture necessary to the decay of the gelatine or animal portion of the bone: for this reason fresh bones are, for a length of time at least, next to useless in the soil. 2. The bones, deprived of fat, are kept in a moist state in heaps for two or three months. Under these circumstances the bones heat or ferment, from the partial decomposition of the nitrogenous matter they contain. Much ammonia is produced, the greater portion of which is retained by the fat still remaining in the bones; a small quantity of this substance always being left, even after prolonged boiling. By this process the bones become softer, can be more easily reduced to powder, and are altogether better suited

for use as manure. 3. Another system, followed in Manchester and other districts where inferior sorts of cloth are manufactured, consists in further extracting the gelatine after the fat has been removed. This is accomplished by boiling under pressure in closed vessels, when the gelatine is extracted, and by evaporation is converted into size. This impure size is used for giving stiffness or "body" to the commoner sorts of woollen cloths. Bones that have undergone this process are of course less valuable for agricultural purposes, since, the greater part of the gelatine being removed, there will be but little ammonia produced when the bones decay in the soil; but as the phosphate of lime is still present, bones of this kind will do equally well for the farmer, provided he can obtain them at a proportionate price.

The value of bones as a manure is chiefly dependent on the large quantity of phosphoric acid, in the shape of phosphate of lime, they contain. It will be remembered that this substance is in most soils present only in small quantities; and as it is required in the development of all cultivated crops, its artificial addition becomes necessary. This is most effectively done by the application of phosphatic manures. A further effect of bones is exerted by the animal matter they contain. This, in decaying, gives rise to ammonia, which greatly assists the action of the phosphate of lime.

Bones are preferred to other more active phosphatic manures in cases where a gentle but continuous supply of phosphoric acid and ammonia is desirable. The effects of bones extend over several years, and are regulated by the state of division, or the size of the fragments of bones supplied. From the slow action of bones, they are well adapted for application to permanent pastures. We may now explain the matter adverted to in a preceding page; viz., the restoration of the fertility of meadow land by the use of bones when ordinary farmyard manure is of no avail. In the case referred to, it is stated that per-

manent meadows had become partially exhausted from the continued grazing of cows, whose milk was disposed of in the production of cheese.

It is known that the curd of milk, of which cheese is manufactured, contains a small but definite amount of phosphorus and phosphoric acid. This substance can only be supplied by the soil which produces the fodder that the cows are fed upon; and as the greater part of this substance received by the cow will be disposed of in the secretion of its milk, but a small quantity only of that contained in the food will be returned in the excrements. Hence, even if all the manure produced be returned to the land, the soil will still be robbed year after year of all that phosphoric acid contained in the cheese carried off the land, and however fertile or prolific in phosphoric acid a soil may naturally be, it must sooner or later feel the effects of this system, and show symptoms of exhaustion. As bones are remarkably rich in phosphoric acid, we can easily account for the renewed vigour of the soil consequent on their addition.

We thus perceive the necessity of adding bone-dust or other phosphatic manures to pasture land employed for the production of dairy produce. In all cases phosphoric acid of some sort must be supplied in addition to ordinary manure, to compensate for the quantities of this material carried away in the shape of milk, cheese, cattle, &c.

Bones are much less employed now than formerly: for many purposes they have been superseded by the more effective "superphosphate." In many cases, however, as for application to permanent pastures and to other crops on sandy soils, bones are still to be preferred.

Superphosphate of Lime.—The use of superphosphate may be regarded as an improved method of applying bone manure to the land. We have stated that the activity of bones in the soil is in direct proportion to the number of fragments into which the bone is broken up. We can easily understand that this should be the case. A com-

pound like phosphate of lime, that is almost insoluble in water, and but slightly soluble in water containing carbonic acid gas, will necessarily afford little opportunity for solution if exposed to the solvent in a compact mass, as in a piece of bone. But if we break up this bone into small pieces before adding it to the soil, a greater surface is exposed to the action of the water, and more of it dissolved in a given time; and consequently a larger quantity of it is conveyed to the plants growing in this soil. By the use of superphosphate we produce this effect in a high degree. On converting bones into superphosphate and now applying them to the land, they are separated into a multitude of particles infinitely smaller than can be prepared by any amount of grinding or other mechanical means. It is to this circumstance merely that the superior effect of superphosphate, as compared with bone-dust, in the soil is mainly due.

An idea of the minute state of division in which the bone material is separated from superphosphate when added to the soil, may be formed from the following simple yet interesting experiment. A small piece of bone is placed in a wine-glass, or any convenient receptacle, and covered with muriatic acid (the spirits of salts of the shops, before noticed), and left for two or three days; by this time the bone will have become quite soft, owing to the extraction of its earthy or mineral portion, which is dissolved in the clear acid liquid. If we now add to some of this clear liquid a little hartshorn, or ammonia, or even common soda, a white, bulky, flocculent substance will separate. This is the earthy portion of the bone in a finely divided state: it may be regarded as bone material broken up by chemical means. The same substance may be obtained by adding a small quantity of any superphosphate to water, allowing it to stand till clear, and testing this watery solution with ammonia, or soda, as in the former experiment.

When bones moistened with water are mixed with

sulphuric acid, or oil of vitriol, much heat and steam with unpleasant-smelling gases are given off, while the bones for the most part dissolve, forming a creamy fluid. On standing, this mixture dries up and becomes solid, and if the process has been properly conducted, forms a friable, loose, moist gray powder. This powder is superphosphate of lime, an article at present manufactured in enormous quantities in this country. The essential difference between this substance and the original bones is, that the superphosphate is for the most part soluble in water. The beauty of this process, however, lies in the fact that not only bones, but other combinations of phosphate of lime, otherwise useless, as the stones and rocky minerals before mentioned, can by this means be converted into superphosphates. For this reason, minerals of this kind are eagerly sought for, and constantly being discovered. Thus we perceive, by the magic of Chemistry, useless stones are changed into fertilizing manures, and these again, by still greater magic, actually become part of our daily food.

The chemical changes involved in the production of superphosphate, from bones or either of the above-mentioned raw materials, may be thus explained :—In all these materials the phosphoric acid is combined with lime in the form of phosphate of lime, or bone-earth, as it is called. Now, it must be stated, that in all chemical decompositions the right of might prevails ; the stronger substance, if so disposed, always driving out the weaker one. Thus, when we add sulphuric acid, or oil of vitriol (which is the strongest of all acids), to the combination of phosphoric acid and lime, called bone-earth, the weaker phosphoric acid is displaced, and the sulphuric acid takes its place, to form sulphate of lime, or plaster of Paris. But in practice, all the lime is not taken from the phosphoric acid by oil of vitriol ; a part of the lime still remains, and forms, with the phosphoric acid, a new combination, called biphosphate, or soluble phosphate of

lime. This change will perhaps be better understood by a glance at the following plan of the operation :—

	Materials employed.	Products.
Insoluble phosphate of lime, as it occurs in bones and minerals, consists of three quantities of lime, and one quantity of phosphoric acid; we may therefore represent it as....	Phosphoric acid Lime	Soluble or superphosphate of lime.
	Lime .... Lime	Sulphate of lime, gypsum, or plaster of Paris.
On adding sulphuric acid or oil of vitriol, two of these quantities of lime are removed.	Sulphuric acid Sulphuric acid	

From this we perceive that in the manure called superphosphate of lime, there is a soluble combination of phosphoric acid, on which its value chiefly depends, and a larger quantity of sulphate of lime obtained as a secondary product. This latter substance is comparatively of little value as a manure.

When phosphate of lime of mineral origin, as from any of the minerals above mentioned, is used in this manufacture, the value of the resulting superphosphate is almost solely dependent on the amount of soluble phosphate of lime it contains. The same will be the case when the superphosphate has been prepared from the substance technically known as "bone-black," or the refuse animal charcoal of sugar-refiners; also that made of bone-ash, a material at present largely imported from South America for the manufacture of this manure. In all these cases the superphosphate produced is purely a phosphatic manure; that is to say, its effects in the soil are entirely due to the phosphoric acid, and in much minor degree to the gypsum contained in superphosphate. But when bones are used in the manufacture, the resulting manure is rendered more valuable by the animal matter, —the gelatine of the bones. A part of this is trans-

formed into ammonia, which, meeting with sulphuric acid, becomes sulphate of ammonia; while of the remainder, a considerable portion is converted into a form soluble in water.

In manufacturing this substance on a large scale, all the insoluble phosphate of lime is not rendered soluble;—a part of it always remains after the process, in its original state. The amount of this unchanged material left in the product depends on the quantity of sulphuric acid or oil of vitriol used in the process, and on the quality of the bones or other kind of phosphate employed. For these and other reasons, the material commonly called superphosphate is a mixture of most uncertain quality, scarcely two samples ever being found alike. The general composition of superphosphates, as well as the extent to which they differ from one another, may be learned from the following examples, selected from a great number analyzed in our laboratory at Cirencester:—

COMPOSITION OF SUPERPHOSPHATE OF LIME.

	1.	2.	3.
Water	20·53	14·40	0·91
Organic matter	14·76	8·93	—
Soluble phosphate of lime	10·31	3·60	25·70
Equal to bone-earth	(16·09)	(5·61)	(40·11)
Insoluble bone phosphate	17·72	6·83	6·68
Hydrated sulphate of lime (gypsum)	28·39	44·23	55·43
Alkaline salts	1·56	2·52	·96
Sand	6·73	19·50	2·32
	100·00	100·00	100·00
Per-centage of nitrogen	·853	1·44	
Equal to ammonia	1·065	1·75	

No. 1 may be accepted as an example of a good superphosphate; it contains about a third of its weight of phosphate of lime, one-half of which is rendered soluble

by acid. The other half of this phosphate of lime may be regarded as unchanged bone material, and, provided the manure has been made from bones, this insoluble phosphate of lime will be of the same value in the soil as bone-dust; but if, as often happens, mineral phosphate of lime has been used in the manufacture, this quantity left unchanged will be worthless, or nearly so, when applied to the land. The essential material is, in all cases, the phosphate of lime soluble in water, and the value of the sample is chiefly regulated by the proportion of this material. The organic matter—the more or less altered gelatine of the bones—depends for its value on the nitrogen it contains, or the amount of ammonia it is capable of producing by decay. For this reason, the amount of nitrogen should always be stated in the analysis of a superphosphate.

The gypsum and common salt are possessed of a certain value; but a much lower one than that of bone material. The water and small quantity of sand and earthy matters are unavoidable impurities, and, of course, must not be taken into account in estimating the value of the manure. This sample, as before stated, represents a superphosphate of fair quality, and should cost about £7, to £7 10*s.* per ton.

No. 2 is altogether the reverse of No. 1. It contains but a small quantity of soluble phosphate, and very little insoluble; an undue quantity of gypsum, and far too much sand. This is an adulterated superphosphate, and is worth but a fraction of the price charged for it. From these examples it will be seen that the value of a superphosphate entirely depends on its quality, and, in most cases, on the proportion of soluble phosphate of lime it contains. Thus a sample like No. 3 is not dear at £12, because it contains £12 worth of fertilizing materials; whereas the sample No. 2 would be dear at £5. It should always be remembered by farmers in purchasing superphosphate, and, indeed, all other kinds of artificial

mixtures, that the dearness or cheapness of a manure is not determined by its price, but by the amount of fertilizing materials it contains, and the degrees of fitness of these materials for action in the soil.

In the case of manufactured manures, like superphosphate for instance, much of their agricultural value depends on the mechanical condition in which they are supplied,—the extent to which their constituents have been pulverized and intermixed. The richest manure, chemically speaking, will be of little use unless it is moderately dry, reduced to fine powder, and its constituents thoroughly incorporated. This must be borne in mind in judging of the value of a manure, and a proportionate price must be allowed for the degree of completeness with which these matters have been attended to. Although in theory the production of superphosphate is a very simple matter, in practice it is found somewhat troublesome, from the difficulty of producing a manageable article; and a great deal of experience and skill are required to prepare a superphosphate of the requisite chemical strength and mechanical condition at a remunerative price. For this reason we would recommend farmers never to attempt to make their own superphosphate, since, in most cases, their efforts will result in the production of a material too wet or too dry,—or otherwise unmanageable, and altogether remote from the character of a good superphosphate. The best plan of obtaining this material is to purchase it of some old-established manufacturer of known respectability, who will readily guarantee its quality. For the reasons above stated, the exact value of a manure cannot be told by judging solely of its composition as revealed by an analysis; on the other hand, we can never arrive at the real value of a manure without an analysis. The perfection of mechanical texture will be useless unless its chemical value corresponds. The value to be attached to mechanical condition must always be added to that depending on the amount of fertilizing materials it contains: thus we

can only arrive at the precise value of a superphosphate by comparing its composition, as shown by analysis, with its external properties.

Superphosphate is generally applied to the root crops in conjunction with well-rotted farmyard manure; the superphosphate being mixed with ashes and drilled in with the seed. In this operation it is good policy to spend extra labour in pulverizing and mixing the superphosphate with the ashes employed, since much of the subsequent effect of the manure will depend on the care taken in its application. Moreover, as remarked on a former occasion, a less quantity of manure properly applied will go as far as a larger quantity carelessly applied. Two or three hundredweight per acre will in most cases be a fair dose, and amply sufficient to supply phosphoric acid and sulphuric acid to all the crops of a rotation.

An excellent method of applying superphosphate in particular cases is by means of the liquid-manure drill.

Superphosphate is particularly adapted for promoting the growth of root crops—turnips, Swedes, &c. It seems to benefit these plants at every stage of their growth. Not the least of the good effects of superphosphate on turnips and Swedes is its undoubted efficacy in hastening the early growth of the young plants. This effect, in many instances, saves the crop from destruction by the turnip fly.

Ammoniacal or Nitrogenous Manures.

Guano.

Let us now direct our attention to those manures employed for supplying particular crops with nitrogen or ammonia. In doing this we shall naturally begin with guano. Guano—that is, Peruvian guano—owes most of its effects as a manure to the ammonia it contains; and the high price of this article is not dear, when we consider the large quantity of this valuable material it con-

tains in a fixed or solid form. By adding 1 lb. of guano to the soil, we supply it with as much ammonia as is contained in 24 lb. of well-rotted farmyard manure.

Guano is a natural product, consisting of the excrement of sea-fowl, more or less altered by fermentation and decay. In certain districts of the tropics, where little rain falls, the coasts and islands frequented by large numbers of sea-birds become covered with accumulations of their dung, which, after spontaneous drying and fermentation, constitutes the material we call guano. Beds of this material have been discovered in several localities, the more extensive being upon islands off the coast of Peru. From this place the greater part of the guano met with in commerce is obtained, and as the climate of this locality is particularly favourable for the preservation of this substance, the guano of this place is not only the most abundant, but of better quality than that found in any other place. The right of importing this kind of guano exclusively belongs to the Messrs. Gibbs and Bright, through whose hands all the Peruvian guano supplied by dealers must have passed.

Most of the Peruvian guano brought to this country is tolerably uniform in quality, but, occasionally, cargoes arrive that have been damaged by sea-water or otherwise, and are sold by auction.

This damaged guano is often purchased at a low price by unscrupulous dealers, who afterwards dispose of it to unsuspecting persons under the name of genuine guano,—which indeed it is, but not of the best quality. For this reason, in purchasing guano, care must be taken to see that the article supplied is really what it is represented to be. But this is not the only kind of imposition one is liable to in purchasing guano; as we shall presently see, the substances offered for sale and purchased under the name of guano are often altogether different from genuine guano, even of damaged quality.

Guano of an inferior description is also brought from

Saldanha Bay, Bolivia, Ichaboe, and, quite lately, from the Falkland Islands, and still more recently, from the Kooria Mooria Islands. The guano obtained from all these places is inferior to Peruvian guano.

The external properties of Peruvian guano are tolerably well known. As generally met with, it is in a moderately dry light powder, interspersed with lumps of harder material. These lumps are often difficult to break, and when broken present a crystalline structure. The colour of guano is generally a light brownish red or fawn-colour. It is also possessed of a peculiar unpleasant smell, which is popularly supposed to be due to the escape of ammonia. But this is a delusion; ammonia does not escape in any appreciable quantity from guano, even when it is exposed for a length of time to the heat of the sun.

That the smell of guano is not due to the escape of ammonia, may be proved by a simple experiment. If we moisten a little guano with sulphuric or any other acid, and now dry the guano, we find that the smell is still present. This could not be the case if it were caused by the escape of combinations of ammonia; since, after the addition of acid, all the ammonia that could escape would have become fixed in the manner described in a former chapter.

Genuine guano is an extremely light substance,—a bushel of it weighing only 68 to 72 lb. Hence, by this fact we are furnished with a rude method of ascertaining the genuineness of a sample of guano; since all other substances that are likely to be used to adulterate guano add to its specific weight.

Before proceeding any further, let us state the composition of guano. The following analyses will convey an idea of the composition of two or three sorts of guano:—

COMPOSITION OF GUANO.

	1.	2.	3.
Water	12·42	12·00	11·54
Organic matter and ammonical salts	52·98	59·11	19·79
Phosphates of lime and magnesia (bone-earth)	25·06	19·31	42·93
Alkaline salts, chiefly chlorides of potassium and sodium	8·26	8·13	4·78
Gypsum	..	..	1·70
Insoluble silicious matter	1·50	1·45	9·36
	100·23	100·00	100·00
Yielding ammonia	17·21	19·30	4·35

From the above analysis of genuine guano we perceive that this substance is remarkably rich in fertilizing materials, nearly every one of its constituents being a material highly valuable for promoting the growth of plants. For this reason guano may fairly be considered as the richest and most concentrated of manures. Most of the complaints occasionally raised against this manure, and the disappointments that sometimes follow its use, may be traced to an injudicious use of this substance, arising from ignorance of the fact that it is too stimulating a manure—too concentrated—to be used but with the utmost caution.

As we notice by glancing at the above analysis of guano, nearly two-thirds of its weight consist of salts and other combinations of ammonia, more than a fourth of which is real or pure ammonia. This portion of guano contains many of the same compounds as are found in the urine of domestic animals, and noticed when speaking of farmyard manure; so that we may regard this portion of guano as urine divested of its large quantity of water. The next important constituent of guano is the phosphate

of lime or bone material: nearly a fourth of its weight consists of this substance. The materials included under the item alkaline salts, consist of potash and soda combined with sulphuric, carbonic, and phosphoric acids. With this latter acid the potash and soda are especially valuable, since in this form they are readily soluble in water.

Thus we perceive that, with the exception of a little sandy and earthy matter, amounting to little more than one part in a hundred, and about 14 per cent. of water or moisture, every particle of good guano is capable of contributing to the growth of plants, and supplying them with the materials required in the production of those compounds on which the value of fertilizing materials depends. Hence we can account for the extraordinary effect a comparatively small quantity of this substance often exhibits when judiciously applied to our crops.

The above remarks apply to Peruvian guano of the best quality, such as can be obtained from £12. 10*s.* to £13. per ton; and this price, though indeed high, is not dear, if we consider the market price of its constituents, or the price we should have to pay for the materials of guano in any other form.

But unless the farmer is careful in buying this material, or if, in mistaken policy, he purchases a sample apparently but slightly damaged, at a reduced price, the substance he uses under the name of guano will possess qualities very different and much inferior to those above described. Guano offers too great a temptation for adulteration to be resisted by unscrupulous manure-dealers: its high price, the facility with which foreign substances can be mixed with it, and the difficulty of recognizing such admixture by persons ignorant of chemistry, account for the fact that guano, of all other artificial manures, is most subject to adulteration.

In many cases this adulteration is but clumsily effected, and can readily be detected by persons acquainted with

the appearance of genuine guano; but occasionally adulterated samples are met with so skilfully mixed, and the natural texture of guano so craftily imitated, that the most experienced judges are deceived by the appearance. In these not unfrequent cases, chemical analysis is the only means at our disposal for detecting the adulteration. In all cases this is the only method of ascertaining the real value of guano. By way of illustration we now insert some examples of adulterated guano that have come under our notice.

EXAMPLES OF ADULTERATED GUANO.

Water	5·33	8·28
Organic matter	3·52	13·11
Oxide of iron and alumina	..	3·59
Phosphate of lime	18·10	2·35
Sulphate of lime (gypsum)	..	15·17
Carbonate of lime (chalk)	69·75	8·00
Chloride of sodium (common salt)	1·75	15·80
Insoluble silicious matter (sand, &c.)	..	34·29
Magnesia	1·35	..
Loss	·20	..
	100·00	100·50
Containing nitrogen	·19	·52
Equal to ammonia	·23	·64

The following simple experiments are often highly useful for enabling one to ascertain whether a sample of guano is adulterated or not:—1. A small quantity of the sample is mixed with quicklime and water to a paste in a tumbler glass or other convenient vessel. A strong smell of ammonia or hartshorn should be given off: the smell will be strong in proportion as the guano is good. 2. A little of the sample is burned on a piece of tin plate over a lamp or a clear fire: the greater part of the guano burns away, leaving a white or slightly gray

ash. If the ash is of a red or brown colour, we may infer that the guano is not pure. Further, this ash will dissolve almost entirely in muriatic acid, if the guano is pure; whereas, in the case of an adulterated sample, a quantity of substance will remain undissolved in this liquid, even after standing for two or three hours.

These tests may be applied with greater precision if we possess a small pair of apothecary's scales. In this case, 100 grs. of guano should be weighed out; this quantity should lose by burning about 60 grs., and the remaining ash, on being tested with muriatic acid, should not leave more than two or three grains of insoluble matter.

In using guano as a top dressing for wheat, especial care should be taken in preparing it for application to the land. The hard lumps should be broken, and the whole substance reduced to fine powder by beating and sifting; further, it should be mixed with two or three times its weight of salt or dry earth, and thoroughly incorporated before being added to the land. The object of mixing with some other substance, as salt or earth, is simply to insure a more even distribution of the guano over the soil; and the better this is effected (by whatever means), the greater will be the effect of the guano on the crops. This uniform distribution over the land, so essential for the successful employment of all artificial manures, is the more necessary in the case of guano; since, by neglecting this precaution, the larger lumps of guano are likely to "burn" the plants, and thus do more harm than good when applied to the crop.

Adulteration of Manures.

Before proceeding to describe the other less important artificial manures, a few remarks on the adulteration of manures and the circumstances that affect their value may not be out of place.

The adulteration of manures, as indeed of all other articles of commerce (especially those in any way used as food or medicine), is a practice that cannot be too strongly condemned ; and it is much to be regretted that the laws of this country afford too many chances for the successful carrying on of this species of fraud.

In the case of manures, their adulteration is attended with several evils besides the more direct one of robbing those who purchase the adulterated articles. The fact of manures being known to be extensively adulterated, tends to restrict their use, and to withhold the good that a more extended use of these materials is calculated to confer both on the farmer and on the community. For the same reason the trade of honest manufacturers is injured and confined.

Under the name of manures, all kinds of mixtures are sold, often worth but a fraction of the price paid for them, and in too many instances altogether worthless.

The frauds practised by dishonest manure-dealers consist of the diluting or weakening of standard manures, as guano, superphosphate, nitrate of soda, &c., by the admixture of less valuable or worthless materials, as sand, sawdust, brickdust, &c. ; also in the fabrication of mixtures from all kinds of cheap refuse and other materials, as tanners' bark, road-scrapings, old mortar, &c. Such mixtures are brought into the manure market as new compounds, under all sorts of high-flown names, which generally indicate properties in every way the reverse of those possessed by the so-called manures they represent. Mixtures of this description are often supported by flaming testimonials, through which many persons are often induced to waste their money on compounds of this description. It must be remembered that even genuine testimonials in support of the character of a particular manure afford no proof of its real or market value, since what may produce a good effect on one soil will not do so on others. The fertilizing effect of a manure on a

soil will be just in proportion as the manure is able to supply what the soil is most in need of. Hence it may happen that a soil is only in need of lime or sulphuric acid: in this case a manure containing plenty of lime or sulphuric acid is all that is requisite to enable the soil to produce a good crop. On such a soil a comparatively worthless mixture of gypsum or sulphuric acid in any other form will produce as good an effect as a valuable superphosphate that contains, in addition to sulphuric acid and lime, the more valuable phosphoric acid; because in this particular case this latter material, generally so valuable, is useless, the soil already containing sufficient phosphoric acid. It is by instances of this sort that a manure often acquires a false character, and is believed to possess qualities to which it has not the slightest claim. Certain natural casualties, to which all crops are occasionally subject,—as very wet or otherwise unfavourable seasons, blight, &c., which interfere with the action of the best manures,—also occasionally favour the character of inferior ones, and for a time conceal their worthlessness.

Hence the money value of a manure cannot be estimated by its effects on a particular soil. Theoretically speaking, all manuring substances are equally valuable, because they are all alike indispensable to the growth of plants; for instance, silica is in this sense as valuable as ammonia; because, unless both of these substances are present, the wheat plant cannot flourish; again, lime is as valuable, because as indispensable, as potash to the growth of nearly all plants. But the money value of these substances is widely different, simply because the relative quantities of these substances in nature are totally unlike; for which reason they can be procured with very different degrees of facility. While silica, lime, organic matter, &c., are abundant in most soils, and are furnished to the plants in inexhaustible quantities, the ammonia, phosphoric acid, &c., are naturally supplied more

sparingly: hence these materials are soonest removed from the soil by the crops grown upon it; and when we wish to renew these materials, we find that we can only obtain them by paying for them; and the price at which they can be procured is of course regulated by the quantity of them supplied in the market. The price we can afford to pay for a manuring material is of course determined by the increase of produce we may calculate upon its producing. Thus the number of substances at present used in artificial manures is limited by the price at which they can be procured. Several salts of high fertilizing value,—as phosphate of potash or phosphate of soda, nitrate of ammonia, phosphate of ammonia, &c.,—would be eagerly bought as manures, could they be supplied at a price consistent with agricultural economy. By the discovery of more prolific sources of materials that can be used in agriculture, certain substances, formerly used for other purposes, find a new application in the way of manures; for instance, until the discovery of guano, or rather its importation to this country, the artificial supply of ammonia to agricultural crops was very limited, simply because all the combinations of ammonia supplied to the market fetched a price far beyond that which the farmer could afford to pay. Again, long after it was discovered that nitric acid was a valuable fertilizing material, its use as a manure was prevented by the high price of its salts: they were in demand for other purposes, and consequently were worth more money than the farmer was able to pay. But comparatively recently, vast beds of a material containing a large proportion of nitric acid have been discovered; so that its market price is reduced, and now comes within the reach of farmers.

The money value of a manure is thus determined by the market price of its constituents. This applies to all natural products, as guano, nitrate of soda, &c. In the case of manufactured manures, as superphosphate, an additional price must, of course, be allowed for the expenses

incurred in its production. Whatever the effects of a manure may be under certain favourable circumstances or on any one particular soil, its real value is still subject to the above standard; and if its composition does not justify the price charged, even though it may happen to produce a good crop, too much will have been paid for it,—simply because the same effects on the same crop might have been obtained by the employment of its constituents otherwise procured at their legitimate price.

The best way of procuring artificial manures is to purchase them of manufacturers or dealers of known respectability, who will readily guarantee the manures they supply to be of a particular strength, as determined by analysis, which they furnish; and the price charged will be according to this analysis. But as the manures manufactured by the best of makers often pass through several hands before they reach the consumer, it is proper, in all cases, that the manure received should be tested, in order that the buyer may satisfy himself of its quality, and that it is worth the price paid for it. This is easily done by taking a sample from two or three of the bags of manure and forwarding it to an analytical chemist of recognized respectability and skill, who will readily ascertain the composition of the manure, and whether it corresponds with the analysis furnished by the dealer. In comparing the results of analyses of manures, differences of two or three per cent. in the contents must not be noticed.

Nitrate of soda is another material largely employed for artificially supplying certain crops with nitrogen. In speaking of the atmosphere, we noticed the existence in the air of minute quantities of a substance called nitrate of ammonia,—a salt that is found to exercise a powerful effect in promoting vegetable growth; and it was stated that the superior efficacy of rain that falls during thunderstorms, in refreshing and invigorating plants, is, in a great measure, due to the nitrate of ammonia it contains. Substances closely analogous to this salt are saltpetre,—the

salt used in the pickling of meat, the proper name of which is nitrate of potash, and the salt now so frequently used as a top dressing for wheat, called Chili saltpetre, or, more properly, nitrate of soda.

Each of these salts contains a large quantity of nitric acid, or aqua-fortis,—the material to which the fertilizing effect of these salts is more immediately due.

As most of us are aware, nitric acid in a separate state is a highly corrosive fluid, capable of dissolving metals, like silver or copper; but when combined with alkalies,—as in the above salts,—its corrosive properties are concealed and overcome, and it becomes a highly fertilizing material, which, like ammonia, supplies plants with the nitrogen they require in the formation of the flesh-forming compounds of food.

It is probable that all the nitrogen received by plants is conveyed to them either in the form of ammonia or nitric acid, and that the nitrogen contained in all the animal or other substances added to the soil as manures, is converted into one or other of these forms before being supplied to the plants; but which of these forms is the best, or which is most favourably received by plants, is not well known; this much, however, is certain, that both of these forms of nitrogen exercise a highly fertilizing effect on plants, and, consequently, are valuable manures.

Nitric acid is found in small quantities in dung-heaps; and wherever animal or vegetable matter containing nitrogen is present with much lime, under favourable circumstances, nitric acid is formed from the nitrogen of the organic matter. In this manner, large quantities of nitrate of potash, or saltpetre, are formed artificially in nitre-beds, as they are called.

Either in an analogous manner, or by the action of electrical currents upon the air, the nitrate of potash found in the soil of certain warm climates, as in the East Indies, is probably formed. Comparatively recently, large beds of a salt very similar to nitre have been discovered in

Chili;—hence, the term "Chili saltpetre" sometimes applied to the nitrate of soda employed in agriculture.

The composition of nitrate of soda may be thus stated:—

COMPOSITION OF NITRATE OF SODA.

	Genuine Sample.	Adulterated Sample.
Water	·93	4·04
Nitrate of soda	95·02	78·97
Sulphate of soda	—	4·62
Chloride of sodium, or common salt	3·24	10·04
Sand and insoluble matter	·81	2·13
	100·00	100·00

Like all other artificial manures, nitrate of soda is often found adulterated: in most cases this is effected by means of cheaper salts of the same character; as, for instance, common salt, glauber salt, or sulphate of soda, &c. As these salts are all crystalline, and in other respects resemble nitrate of soda, these substances cannot be detected by any means short of an analysis.

Nitrate of soda is generally used as a top dressing for grain crops; and the same precautions for insuring its even distribution over the soil should be attended to as in the case of guano.

Soot.—Leaving the more valuable and highly concentrated nitrogenous manures, let us now consider a few cheaper refuse substances that belong to the same class,—that possess the same qualities in a less degree.

An ammoniacal manure in common use is soot. This substance is chiefly useful on account of the ammonia it contains in the form of salts. The smoke of lamps and coal fires consists of minute particles of unaltered charcoal, with other intermediate products of combustion. All the charcoal, or carbon, of fuel that takes part in the

actual combustion, is converted into carbonic acid gas, as stated in a previous chapter. But when much carbon is present in a fuel that burns with flame, a great deal of this carbon is carried off in the shape of smoke: from this smoke the carbon is readily deposited upon any cold object. In this finely-divided shape carbon is technically called lampblack, and is an article of extensive manufacture. The soot that accumulates in our chimneys, where coal is used for fuel, is an impure variety of lampblack. It is to these impurities, however, that soot chiefly owes its agricultural value. In speaking of the sources of ammonia, it was stated that one of these sources is coal. Coal contains variable quantities of nitrogen in organic combinations;—when the coal is burnt, this nitrogen passes off in the form of ammonia. Coal also contains sulphur or brimstone. When this substance is burned in the coal, a part of it is volatilized in the form of sulphurous acid, which, meeting with the ammonia simultaneously liberated, effectually fixes it and retains it in the soot.

We may satisfy ourselves of the presence of ammonia in soot by testing it with lime in the manner described in speaking of guano: by this treatment the soot will evolve a strong smell of ammonia or hartshorn. Although ammonia is the more valuable constituent of soot, it contains other substances, which, in a minor degree, contribute to its usefulness as a manure. Some of the sulphurous acid gas, in the presence of the finely divided carbon of soot, becomes converted into sulphuric acid, or oil of vitriol; this, in its turn, combines with lime from the mortar of the chimney: hence we find in soot variable quantities of sulphate of lime or gypsum, a substance which, as we shall presently show, is of much service in the soil. The value of commercial soot is regulated almost entirely by the proportion of ammonia it contains, the average quantity of this substance being about 2 or 3 per cent.

Gas Liquor.—While speaking of soot, and remarking that its value as a manure depends on the presence of certain compounds arising from the combustion of coal, we are naturally reminded of the use, as manures, of the same compounds, found on a large scale in the process of gas-making.

When coal is heated in closed vessels for the purpose of converting it into gas, nearly all the nitrogen it contains passes off in the shape of ammonia, along with the other gases simultaneously produced. In undergoing the process of purification to adapt it for illuminating purposes, the coal gas is separated from this ammonia and other impurities, part of which are retained by water through which the gas is made to pass. This water is technically called "gas liquor," and is the source from which most of the ammonia found in commerce is prepared. This gas liquor consists of water containing variable quantities of several salts of ammonia, dissolved in it with other impurities. To obtain this ammonia, the gas liquor is evaporated with some strong acid, as sulphuric acid, or oil of vitriol. By this means the ammonia is fixed, and when dried up constitutes the salt called sulphate of ammonia,—a substance often used by the farmer for the same purpose for which he uses guano or nitrate of soda. This salt is also largely employed by manure-makers in the preparation of wheat manures, grass manures, and other mixtures of the sort.

In districts in the immediate neighbourhood of gas-works, the gas liquor itself is occasionally used as a manure, and by judicious management can often be employed with great advantage upon grass land and other crops. The use of this fluid as a manure is attended with a certain amount of danger, since, unless it is sufficiently diluted with water before application to the land, it is liable to produce a contrary effect to the one desired; in other words, it is apt to scorch the crop. This effect is due to the salts of ammonia it contains, which always exhibit an injurious

effect on vegetation when too bountifully applied. It must, however, be remembered—in extenuation of the character of gas liquor as a manure—that guano occasionally produces the same injurious effect, if carelessly applied. The proper way to use gas liquor is to dilute it with water until no unpleasant taste is perceptible, and in this weak state supply it to the land by means of a liquid manure distributor. The employment of this material as a manure is, of course, limited to the districts in the vicinity of gas-works; since, on account of the large proportion of water belonging to it, its conveyance to any distance is impracticable, the expense of carriage soon amounting to more than the whole mixture is worth.

Gas lime is also occasionally used as a manure; but, generally speaking, apart from its value as a variety of lime, or as a source of gypsum, it is of little value as a manure. We mention it in this place because a belief is common that this substance contains more ammonia than gas liquor. It need scarcely be said this is not the case, simply because caustic or quicklime, the prevailing ingredient of gas lime, expels ammonia from any of its combinations. It is on this fact that the test for ammonia, described in an early chapter, and to which we have several times referred, is based: hence gas lime cannot—neither does it—contain any appreciable quantity of ammonia. The use of this substance in localities where it can be procured at a very cheap rate, as a source of lime and of sulphuric acid, may be recommended.

Animal refuse manures, as wool-refuse, or shoddy, leather-refuse, glue-refuse, butchers' offal, blood, and animal matter of all descriptions belong to the class of nitrogenous manures. By decay in the soil, these substances furnish ammonia from the nitrogen they contain. The value of these substances, though dependent on the proportion of nitrogen they contain, is qualified by the degree of facility with which this nitrogen is liberated,

or, in other words, upon the readiness with which they undergo decay when added to the land. Thus wool-refuse, or the sweepings of cloth factories, contains a considerable amount of nitrogen; but as this material decays but slowly, and remains unchanged for a length of time when added to the soil, it is of little value as a manure; it may, however, by suitable means, be fermented previous to being added to the soil, and its usefulness by this means greatly increased.

Amongst this kind of manures mixtures are occasionally met with in the manure market, called "animal guanos," or "flesh manures." As far as we may judge by the samples of this substance that have been analyzed, they seem to possess claims to the title of good manures. Refuse flesh and offal is procured from Buenos Ayres and other districts in South America, where animal matter and bones are of little value.

The blood of animals is well known to be a most powerful manuring substance. It contains nearly all the essential materials required for the growth of plants: hence, if this substance can be economically procured, its use as a manure may be recommended. We mention this material amongst manures, not so much because we believe its use in this way to be very extensive, but because the term "blood" has lately become a favourite prefix with manure-dealers, who, aware of the popular belief in the richness of blood as a manure, attach this term to mixtures of which the blood of animals forms a very small proportion.

There is no necessity for us to enter further upon the individual merits of the various refuse manures. It is sufficient to state that in all cases their value depends on the price at which they can be procured, or rather, their price as compared with the market value of their constituents. For instance, if a farmer can obtain the same quantity of nitrogen—in the shape of blood or any other refuse animal matter—at a lower price than he can in the

shape of guano or nitrate of soda, he will do well to avail himself of the opportunity, and purchase them. But, unless the quantity of fertilizing material contained in these substances is equivalent to the price paid for them, they are dear, however low this price may be.

Gypsum is the mineralogical name of the substance popularly known as plaster of Paris, the chemical name of which is sulphate of lime. As the latter name indicates, it is composed of sulphuric acid and lime; and since both of these substances, especially the former, are occasionally deficient in soils, the application of gypsum is often attended with good effect on the land. Gypsum is found to exert a peculiarly favourable influence on all leguminous plants, as clover, pease, &c. Towards these plants, gypsum often acts as a powerful manure; and in soils deficient in sulphuric acid and lime, the addition of gypsum to crops of this kind is to be recommended.

Another valuable property of gypsum is its property of fixing ammonia. It is found that when the volatile carbonate of ammonia meets with gypsum or sulphate of lime, a mutual change of composition results, and sulphate of ammonia and carbonate of lime are formed. Sulphate of ammonia being a permanent salt, the ammonia is now fixed or safely preserved from loss by volatility. As carbonate of ammonia exists in the air, and is formed from manures, this property of gypsum greatly adds to its agricultural value. In soils containing a fair quantity of lime, the quantity of this gypsum can be increased at will by the addition of any soluble salt of sulphuric acid, as *sulphate of soda*, for instance. The sulphuric acid soon leaves the soda, to become sulphate of lime or gypsum.

Common salt must not be omitted in a list of substances used as manures, although its claim to this rank is not so well established as those of the materials hitherto described. A great diversity of opinion seems to exist respecting the value of salt as manure; while

some persons extol its use in extravagant terms, others, apparently well able to judge, as strongly condemn it. We suspect these apparent discrepancies in the results of manuring with salt might be explained in a manner similar to that which so happily sets things at rest in the fable of the chameleon. Salt is known to act very differently on different soils. Where salt is absent in the soil, its artificial addition has been known to produce striking effects; but as in most cases the soil already contains enough of this substance, a further quantity is followed by no good result. However, the use of salt as an occasional manure, as a means of destroying insects, and for other purposes in agriculture, is certainly to be recommended. Salt, or its elements, are found in nearly all cultivated plants,—from this we infer that the presence of salt in the soil is necessary to the healthy growth of plants; but its artificial addition is seldom necessary, since a constant supply of this material to the soil has been provided for by nature. It has been noticed that the rain that falls in any open part of the country generally contains traces of common salt: this is supposed to be derived from the sea, in the manner before noticed in speaking of salt as a constituent of the soil.

The plants that require most saline matter are bulbous-rooted plants, as turnips, Swedes, and especially mangolds: this latter root is often benefited by a dose of salt, in addition to the superphosphate generally supplied to this crop. For this reason the manures sold as special manures for mangolds, generally contain a considerable proportion of salt. Salt is admirably adapted for diluting the more valuable manures, as guano, nitrate of soda, &c., as directed in a former page of this chapter.

Having now described the composition and more prominent characters of most of the materials employed as artificial manures, in conclusion we may remark, that of these, or analogous substances, are prepared all the mixtures supplied under the names of special manures for

turnips, wheat, grass, mangolds, &c. Many of these mixtures are valuable manures, and, when properly used, calculated to produce a much better effect than any one of the above-described simpler manures. In many cases these mixtures are prepared on scientific principles, and their ingredients arranged in the proportion found by numerous well-conducted practical experiments to be best adapted for promoting the growth of the particular crop they are intended to benefit. Hence, if mixtures of this kind can be procured of respectable manufacturers, it may often be advantageous to employ them in preference to any of the before-mentioned simple manures. It must, however, be borne in mind that all mixtures of this description are subject to the same standard of value as that mentioned in speaking of superphosphates; namely, that the price charged for the manure will only exceed the market price of its constituents by the cost of manufacture and the amount of a fair profit. Many of these compound manures found in the market are equal to this standard, and fully worth the price demanded for them, the amount of fertilizing materials they contain being even greater than could be obtained by the farmer at the same price in any other form.

On the other hand, it must be remembered that mixtures of substances are constantly met with called "fertilizers," and all sorts of high-flown names, but whose value is but a fraction of the price demanded for them, and which too often consist of materials altogether worthless. Compounds of this sort, of alleged marvellous fertilizing power, are often sold in small packets at extravagant prices. It need scarcely be said, articles of this sort are simply contrivances of designing speculators for fleecing unsuspecting persons. It may be recollected as a rule without exception, that any manure possessed of extraordinary fertilizing power will contain in corresponding quantity those materials on which the luxuriant growth of plants is known to depend, as no magic is yet dis-

covered for making plants grow by any other means. Thus we perceive that artificial manures are possessed of peculiar merits altogether distinct from those of farmyard manure; and that while these substances are highly useful —we may say indispensable in the present system of farming—they can never be used in place of farmyard manure, but always as additions and auxiliaries to this material. The manure produced on a farm should contain all the fertilizing elements extracted from the land by the crops raised upon it, with the exception of those contained in the grain, cattle, or other produce sold off the farm. Hence if the manure made on the farm has been properly preserved, we can return to the land, in this shape, all the materials borrowed from it for the growth of our crops, except those carried away in the manner above noticed. To make good this deficiency we should employ artificial manures; since in these we possess a ready and convenient means of restoring to the soil those more essential constituents permanently removed from it by the produce sent to market. The soil of a farm may thus be regarded as a manufactory of Nature, in which, from certain raw materials, as phosphoric acid, ammonia, &c.—with those supplied by the atmosphere and water—she prepares grain, beef, mutton, and all other kinds of agricultural produce. While on some soils an inexhaustible supply of these materials (with the exception of ammonia) exists, and the business of the cultivator chiefly consists in preparing the ground, and assisting Nature to avail herself of these materials; on most soils, these raw materials must be supplied in the shape of farmyard manure, guano, superphosphate, or other manures. In either case, the farmer holds the position of attendant or curator to Nature, who rewards him in proportion to the diligence and skill he displays in attending upon her.

CHAPTER VII.

VEGETABLE PRODUCE OF THE SOIL.

We have already glanced at the general economy of vegetable life, and the chemistry of the elements of which all plants are composed. We have also briefly described the composition of the more common products of vegetable growth, or at least of those that belong to feeding materials. It has been mentioned that the vegetable productions used as food for man and animals consist of mixtures of compounds called by chemists proximate principles, but which are better known by their familiar names of gluten, starch, sugar, woody fibre, &c. These compounds, as we have seen, vary considerably in their usefulness in the animal system; and as their relative proportions also vary most widely in different kinds of produce, it becomes necessary to learn the proportion of these several compounds that occur in cultivated crops before we can form an idea of the value of these crops, and their fitness for particular purposes. It is also necessary to inquire into the individual characters and habits of the various cultivated plants, the soils best suited for them, and the kinds of manures best calculated to promote their vigorous growth. We shall do this most conveniently by following the natural classification, which may be thus stated:—

Cereal crops...... Wheat, barley, oats, rye, &c.
Root crops ...... Swedes, turnips, mangolds, carrots, &c.
Leguminous crops Pease, beans, vetches, sainfoin, &c.
Fodder crops ..... Grass, hay, clover, &c.

We will now proceed to consider the composition and general economy of each of these kinds of plants, beginning with the cereal or grain crops.

The plants comprised in this important division belong to the natural family of grasses. We may therefore regard wheat, oats, barley, &c., as superior and highly-cultivated grasses. The distinguishing character of these plants is, the production of their seeds in regular bunches, or ears, at the end of a long, upright, hollow stem. In order that this slender stem may possess the requisite strength and rigidity for supporting the comparatively heavy weight of the ripe seeds, it contains a large quantity of the mineral glass-like substance silica. The stems of these plants are remarkable for the large proportion of silica they contain: for this reason these plants are sometimes called "silica plants." The composition of the stem of these plants is as follows:—

COMPOSITION OF STRAW.

	Wheat Straw.	Barley Straw.	Oat Straw.
Water	14·23	14·30	12·06
Flesh-forming matters	1·79	1·68	1·63
Respiratory and fatty matters	31·06	39·98	37·86
Woody fibre	45·45	39·80	43·60
Mineral matters (ash)	7·47	4·24	4·85
	100·00	100·00	100·00

The seeds of these plants are extremely rich in feeding material: the seed of wheat is probably the most nutritive vegetable product. These seeds or grains consist of a white hard substance, inclosed in several shells or husks: when ripe, the grain easily separates from the outer sheath, which remains attached to the stem or straw. As brought to market by the farmer, the grain consists of a hard white substance, inclosed in a scaly covering. The

relative proportion of straw and grain produced by these plants is, of course, different in each species; but apart from this regular variation, it also differs in the plants of one species grown under different circumstances, being influenced by climate, soil, mode of culture, manure employed, variety of seed, &c.

COMPOSITION OF THE GRAIN OF

	Wheat.	Barley.	Oats.
Water	15·26	14·65	13·09
Gluten or flesh-forming material	11·64	10·84	11·85
Starch, &c. (heat-giving principles)	68·74	68·31	63·34
Woody fibre..................	2·61	3·45	7·00
Inorganic matter (ash)	1·75	2·75	2·72
	100·00	100·00	100·00

Wheat.—We will now separately consider the more prominent characters of each of the above kinds of grain crops, beginning with wheat. We must all agree in placing wheat at the head of all cultivated crops. It deserves this distinction from the fact of its being the origin of our daily bread, the source from which the chief part of the food of millions of human beings is directly obtained. As the grain of wheat is an article of such demand, it necessarily becomes the most valuable product of the farm; for this reason the wheat crop is usually—in this country at least—the primary object for which the land is cultivated; and nearly all other crops are subservient to this one.

It is the business of the miller to convert the grain into flour, and in most cases to remove the bran or inner shell of the grain. The flour thus produced is of several qualities, depending not only on the kind of wheat from which it has been prepared, but also on the treatment it has received at the hands of the miller. Each kind of flour is called by some technical name, indicating its

degree of strength and colour, or freedom from husk, &c. Into the details of the process we need not think of entering, as it is sufficient for our present purpose to understand merely the general composition of white flour, which may be thus stated :—

AVERAGE COMPOSITION OF

	Wheaten Flour.	Oatmeal.	Bran.
Water	13·50	13·09	12·86
Flesh-forming substances	11·48	15·68	13·80
Fat and heat-producing substances	73·52	68·17	5·56
Woody fibre	0·68	1·89	11·50
Mineral Matters (ash)	0·82	1·17	6·11
	100·00	100·00	100·00

Of these constituents the gluten is by far the most valuable, and it is on the larger quantity of this substance present in wheaten flour, that its superiority, compared with that of other grain, depends. It is the amount of this substance that chiefly determines the "strength" of the flour, and its fitness for making into bread; the value of flour is, therefore, mainly dependent on the proportion of gluten it contains. It will be remembered that gluten is one of the complex vegetable substances which contain nitrogen with smaller quantities of phosphorus and sulphur, in addition to the oxygen, hydrogen, and carbon of the more abundant but simpler vegetable products: its separation from flour by washing has also been described.

The bran or husk of wheat is also very rich in nourishing materials, particularly in the more valuable mineral constituents of food—the phosphoric acid, magnesia, and other bone-forming substances. By glancing at the preceding table, we perceive that the bran of wheat is even richer in nourishing materials than the flour. For this

reason, the meal of wheat consisting of the bran and flour together, makes a more wholesome description of bread—at least, for persons whose digestion is vigorous—than white flour alone. Hence, the complete removal of bran from wheat meal is a refinement of manufacture that cannot always be considered an improvement, at least so far as the production of a nourishing food is concerned.

On learning the composition of wheat, and considering the large quantity of nutritive materials its seeds contain, we can no longer wonder that it should require for its growth a soil rich in fertilizing materials, or that it should exert an exhaustive effect on the land. For this reason wheat thrives best on a strong land; *i. e.*, land naturally rich in mineral fertilizing materials, and requiring only working and tilling, to yield these materials to plants. On soils of this description,—and to a less extent on lighter land,—ammoniacal manures are found greatly to favour the growth of wheat. These manures supply the nitrogen requisite for the formation of the gluten of the grain, and at the same time stimulate the plants to seek a proportionate quantity of the other kinds of material the plants require.

Barley is subject to the same causes of variation in quality as those that affect the wheat crop; as soil, season, mode of culture, &c. Barley is found to flourish best on light rich soils; and although a heavier crop may be grown on strong land, the finer sorts of barley are always grown on light soils. By a glance at the above table we perceive the constituents of the grain of barley are the same as those of wheat, the proportions of them only being different: we notice that barley contains less gluten and more starch. For this reason the meal of barley is unfitted for making bread; at least, the bread made from it is "heavier," less porous and wholesome than that of wheat flour. The chief application of barley is for the production of malt. It is particularly

adapted for this purpose from the large amount of starch it contains. By the process of malting, this starch is converted into sugar; and by drying, the sugar is preserved from further alteration by putrefaction. The early stages of malting consist in exciting a premature germination in the seeds of the barley. By sprinkling with water, and keeping them at a particular temperature, the seeds begin to sprout or germinate, and put forth the rudiment of a root—the process is now arrested by drying. By this treatment we imitate the natural germination of the seeds in the ground. In both cases the chemical changes in the seed are the same, and may be described as follows: a portion of the gluten first undergoes change, and is converted into a substance called diastase. This diastase may be regarded as a natural yeast or ferment, which communicates the tendency of alteration to the starch also present in the grain. The starch is now transformed by a simple change into sugar, which is provided for the support of the infant plant. A beautiful natural arrangement may be traced in this series of changes that take place during germination. During the first stages of the existence of the embryo plant, some kind of food must be provided to support it until it is able to collect food for itself from the surrounding soil. The food best suited for this purpose is yielded by sugar; but as sugar, if provided in the ripe seed, would quickly undergo spontaneous changes, and soon disappear, the materials only of sugar are provided, in the shape of starch. This substance is far more permanent than sugar, being insoluble in water, and less liable to change. At the time the immature plant shows symptoms of vitality, a substance is produced whose peculiar property is its capability of transforming starch into sugar. Thus sugar is formed only at the time it is required, and the loss that would follow its formation at an earlier period prevented.

Oats contain the same materials as wheat and barley,

but somewhat differently arranged. The composition of this grain may be judged of by the foregoing analysis.

Leguminous crops, as pease, beans, vetches, sainfoin, clover, &c., all partake of the character of the pea, which may be accepted as the type of this family of plants. The prevailing mineral constituent of these plants is lime: for this reason they are sometimes called "lime plants." As we might for this reason expect, these plants flourish most luxuriantly on lime soils, and are cultivated most successfully in limestone districts. For the same reason, the addition of lime to soils containing but little of this substance greatly favours the growth of these crops. Another mineral constituent required by these plants is sulphur: hence the addition of some combination of sulphur is generally attended with benefit to a crop of this description. A substance well fitted for this purpose is gypsum, or plaster of Paris. This compound, as already noticed, contains sulphuric acid and lime, and on this account may be regarded as a special manure for leguminous plants.

Many of these crops are cultivated as much for their stems and leaves as for their seeds. Their employment in a green state as fodder for cattle will be considered amongst other fodder crops. For the present, we need only direct our attention to the properties of their seeds.

The seeds of beans, pease, and other plants of this group, are highly nourishing feeding materials. Like the grain of the corn plant, this superior nutritive value is due to the large proportion of nitrogenous or flesh-forming materials they contain. In these seeds the nitrogenous matter is not gluten, as in the case of grain, but consists of a peculiar vegetable principle called legumen, or vegetable casein: this latter name is given to this compound from the fact of its resembling in its chemical properties the casein or curd of milk. We shall better understand the composition of the plants by glancing at the following table.

COMPOSITION OF PEASE, BEANS, AND LENTILS.

	Pease.	Field-beans.	Lentils.
Nitrogenized or flesh-forming constituents	23·4	23·3	24·0
Substances free from nitrogen, fitted to support respiration, and to lay on fat—			
a. Starch, sugar, fat, &c.	50·0	48·5	52·0
b. Woody fibre	10·0	10·0	9·0
Ash (bone materials)	2·5	3·4	2·5
Water	14·1	14·8	12·5
	100·0	100·0	100·0

Root crops, as Swedes, turnips, mangolds, carrots, &c., are cultivated solely for their roots, or rather bulbs. The habit of these plants is to gather from the soil, during the earlier stages of their growth, a larger quantity of nourishing materials than they require for present use. This extra quantity of food they store up and accumulate in their bulbs, and it is afterwards disposed of in maturing their seeds, during the later period of their development. Thus we learn that during one period of the growth of these plants the bulbs continue to increase in size, and to become richer in feeding materials up to a certain period, when a change in the reverse direction takes place, and the bulb is called upon to supply materials for the sustenance of the other organs of the plant. Hence we see the necessity of gathering the roots or bulbs when fully matured, in order to obtain the maximum quantity of feeding materials. If we leave them longer than this, the amount of woody substance in the root increases, and the root becomes less nourishing; and when the plants are allowed to perfect their seeds, the bulbs are found after the operation to consist chiefly of woody matter; everything they contained in any way useful as animal food, having been extracted for supplying material in the production of the seeds.

Root crops are generally more difficult to raise, and require more care for their successful cultivation, than the crops before described. This is because these plants are more subject to natural casualties, sooner affected by disease, blight, and unfavourable seasons, than those of other crops. Root crops flourish best on light soils that are neither too wet nor too dry: the roots are rendered watery and hollow by too much damp, and are equally susceptible of injury by drought. Hence the produce of this crop is often more affected by the season than by other circumstances within our control. We have before remarked that the turnip plant is unable to gather its food from any portion of the soil remote from the seat of its growth. In all the plants of this group the roots are less developed and fewer in number than those of most other kinds of cultivated plants; for this reason we must supply them with material for their growth in a form that will admit of its ready appropriation.

Since the root crop, of all others in the series of a rotation, is least able to collect its food from the substance of the soil, we generally supply the manure to this crop, and give these plants the benefit of first choice, so that they help themselves to all they care to possess, while the remnants are left for the following crops. The manure usually applied to root crops is well-rotted farmyard manure and superphosphate: the latter substance is frequently employed alone; but in this case the farmyard manure must be added previously, or at some other period of the rotation.

Superphosphate of lime is particularly adapted for promoting the growth of root crops, especially Swedes and turnips: it acts chiefly by supplying these plants with abundance of phosphoric acid at the period they seem to require it most, viz., during the very early stages of their growth; and, as before noticed, an additional advantage is secured by the use of superphosphate, from the vigour it imparts to the young plants, which,

thus strengthened, are better able to resist the attacks of the turnip-fly. Besides phosphoric acid, in a form that can be readily assimilated, these plants require plenty of the alkalies potash and soda. Hence, in soils naturally deficient in these materials, the addition of common salt, or of sulphate of soda, or any other alkaline salt, may be expected to benefit this crop. Mangolds particularly require a large quantity of alkaline matter; so that the addition of common salt with the other manures applied to the mangold crop, will in most cases be found to increase the produce.

The successful cultivation of the root crop, particularly Swedes and turnips, requires more than ordinary care and experience; and the condition of this crop on a farm displays as much as anything else the skill and ability of the farmer. Apart from the natural casualties to which this crop is peculiarly liable, its growth can be regulated to a great extent by proper care and attention; for much depends on the time of sowing and the state of the weather and of the ground at this period: an opportunity lost at this time will affect the future produce. Again, a great deal depends on the quantity and quality of manure employed, or on the proper regulation of the manure to the capability of the soil. A soil of a certain quality, depending on its chemical constitution and mechanical condition, will produce its maximum produce of roots by the addition of a certain quantity only of manure. If this quantity is exceeded, the excess, instead of adding to the produce, as might be expected, diminishes it, by exciting an undue development of leaves at the expense of the bulb; in other words, the higher the state of culture of a soil, the more manure may be used upon it, with the expectation of this manure producing a corresponding amount of produce.

Root crops are almost exclusively cultivated for feeding cattle, and generally supplying the stock of the farm during the winter, when no green food is to be had. We

may therefore regard this produce as a portion of the raw material of mutton and beef: at the same time, it supplies material for the manufacture of manure. Before proceeding any further, let us make ourselves acquainted with the composition of these roots.

AVERAGE COMPOSITION OF ROOTS.

	White Globe.	Swedish Turnip.	Mangold.
Water	90·430	89·460	87·78
Flesh-forming substances	1·143	1·443	1·54
Sugar, pectin, gum, &c.......	5·457	5·932	6·10
Woody fibre................	2·342	2·542	2·50
Inorganic matters (ash)......	·628	·623	·96
	100·000	100·000	100·00

We are astonished at the enormous quantity of water in these roots; in round numbers, nine-tenths of this produce consists of water, or, in the case of Swedes, 100 lb. of roots, in the state they are usually stored, contain but 11 lb. of dry matter. On becoming acquainted with this fact, we can no longer wonder at the large quantity of these roots consumed by cattle: the animals must eat 100 lb. of Swedes to get 11 lb. of real food. The dry substance of these roots consists of feeding materials that are soluble in water, as sugar, a large proportion of pectin or jelly-like substance, as well as the more valuable flesh-forming materials. It also contains a smaller quantity of insoluble matters, all of which, with the exception of the woody fibre, are digestible and nutritious. We also notice that of the three above-named roots, the Swede contains less water and more feeding material than the white turnip; moreover, the dry substance of this root contains a larger proportion of flesh-forming material than that of the white turnip. Hence we can account for the well-known superiority of the Swede as a general feeding

material. Mangolds are distinguished by the large quantity of sugar they contain. It will be remembered that sugar is one of the substances capable of producing fat in the animal system: thus the superiority of these roots for fattening beasts is explained.

Fodder Crops.

Under this head we include grass and hay, clover, sainfoin, Italian rye grass, and green food, as rape, mustard, &c.

Grass and Hay.—The green herbage that in most places covers the soil in a state of nature, consists, for the greater part, of different sorts of grasses more or less adapted for affording sustenance to herbivorous animals. We may therefore regard grass as the food provided by nature for the support of this class of animals; and, as in all cases the arrangements of nature are complete and perfect, we cannot be surprised that grass and hay should be a fodder upon which all kinds of cattle thrive.

Could we obtain at an economical rate enough of these materials to feed our cattle, no other description of fodder would be requisite. But as this is seldom the case, and as by the present system of agriculture it is more profitable to cultivate other kinds of fodder crops, grass and hay, in most cases, form but a small portion of the fodder supplied to stock. At the same time, grass and hay are justly esteemed as choice articles of cattle food; the latter especially, when it can be advantageously obtained, is, in most cases, to be preferred to other sorts of winter fodder; and for this reason hay is generally preserved as a material to be sparingly and judiciously used at critical periods.

Two varieties of grass and hay are usually met with. 1. That produced in permanent meadows, where the soil is exclusively set apart for the growth of this produce.

2. That raised from artificial or temporary meadows, periodically cultivated in a rotation of crops. In both cases the grass is either consumed in a green state by cattle put to graze on the land, or is preserved by drying, in the shape of hay.

The produce of temporary pastures is generally considered less valuable as feeding material than the grass or hay of permanent meadows; while the former is often more abundant and profitable, the latter is sweeter and finer, and holds the first rank in the list of fodder crops.

The quality of permanent pastures probably varies to a greater extent than any other kind of cultivated land. While some districts are remarkable for the richness and luxuriance of their grass land, and have become notorious for the superior quality and abundance of every sort of produce raised from this kind of land, in other districts the natural pasture is poor and scanty, hardly capable of affording a subsistence to the animals kept upon it. These differences in the productiveness of pastures are due to a variety of circumstances besides the more immediate one of difference of soil: the age of the pasture, —the treatment it has undergone,—the species of grasses growing upon it, and especially the state of the soil in regard to water. All these causes may take part in altering the natural capabilities of the land. Amongst the causes that lessen the productiveness of pasture land, the presence of stagnant water holds a prominent place. Land that, from imperfect drainage, contains stagnant water, is found to encourage the growth of coarse, sour species of grass, deficient in every useful quality; and although the soil may contain the elements of fertility, yet in the presence of stagnant water these kinds of grasses will prevail. By draining such land, the inferior grasses will slowly disappear, and give place to a sweet, wholesome herbage. This desirable change may often be hastened by the addition of the seeds of the grasses we

wish to raise, as well as the manures best fitted for affording them nourishment. It is only when stagnant that water exerts this injurious effect on grass land. Provided means exist for its removal when necessary, the flooding of meadow land by water is, in most cases, followed by an increase both in the quality and quantity of the grass. Hence, whenever practicable, the practice of irrigation is eagerly resorted to as a means of increasing the produce of meadow land. The properties of water, on which its usefulness in this operation depends, have been already described.

The composition of grass and hay may thus be represented:—

AVERAGE COMPOSITION OF NATURAL GRASSES.

	Grass.
Water	68·33
Albuminous or flesh-forming principles	4·86
Respiratory matters, starch, gum, sugar, &c.	10·56
Fatty matter	·79
Woody fibre	12·60
Mineral matters (ash)	2·86
	100·00

	Meadow Hay.
Water	14·61
Flesh-forming constituents	8·44
Respiratory and fatty matters	43·63
Woody fibre	27·16
Mineral matters (ash)	6·16
	100·00

The above tables may be accepted to represent the average composition of grass and hay. It will be seen that in fresh grass the quantity of water is very large, although less than in turnips, Swedes, &c. The dry substance consists for the greater part of respiratory or fat-producing substances, and woody fibre. This latter substance being indigestible in the animal system, must not be taken into account in estimating the value of feeding materials. Amongst the former substances we find fatty or oily matter, a substance that materially adds to the value of grass and hay as a feeding material: there is also a considerable portion of the more valuable albumen or flesh-producing compounds. The ash or mineral

constituents are also large in comparison with other fodder crops.

In hay we find the same materials in greater proportion. As the hay contains much less water, it is, of course, richer, weight for weight, than grass. The qualities of hay depend very much on the age of the grass at the time of cutting, as well as on the treatment it has undergone during its conversion into hay. It is well known that young grass is more nutritious than that which has passed maturity. This is explained by the fact that the quantity of indigestible woody fibre rapidly increases as the plants arrive at full growth. For this reason, it is desirable to cut the grass intended for hay as early as possible; since a delay at this critical period may greatly reduce the nutritive value of the crop of hay. The quality of hay is often deteriorated by prolonged wet weather, and other circumstances over which the farmer has no control. In the case of damage by rain, the soluble matters are washed out, in some cases leaving little else than the woody fibre of the stems. Moreover, in these cases, the hay is always more or less injured by incipient decay.

The growth of the grasses tends to improve and enrich he surface-soil, and, as before hinted, is one of the means provided by Nature for the amelioration of nearly all crude or new soils. By the successive growth and decay of the plants composing the natural herbage,—which sooner or later springs up whenever masses of earthy material are exposed to the weather, the upper layer of earth accumulates, is slowly converted into a soil more or less capable of rewarding the labour and skill of the husbandman.

The production of a fertile soil from a barren surface of earthy material by the prolonged growth of grass, is strikingly exemplified in the case of several of our finest pasture lands, which in many cases rest upon beds of clay, whose surfaces have by this means become covered by a

rich, deep mould. The habits of the grasses on which this useful effect depends may, to some extent, be explained as follows: these plants are remarkable for the large quantity of roots they produce during their growth, and for their ability of collecting the fertilizing materials existing in the atmosphere. By the large surface of leaves these plants expose to the air, they are enabled to collect the greater part of the carbonic acid they require for their growth from the air; and, to a less extent, also, the more valuable ammonia. The mineral substances they require are supplied by the soil, as in the case of other kinds of plants; but many of these grasses possess the power of seeking for the mineral food they require from great distances; they thus ransack the remoter portions of the soil, and convey its hidden treasures to the surface. On the decay of these plants, the materials they have collected from the air are left in the soil, which is thus made richer in organic matter, or humus, while, at the same time, the surface-soil is also enriched by the mineral fertilizing materials brought from the lower portions of the soil. The humus and organic remains thus contributed to the soil by these plants, apart from their chemical effect on the growth of subsequent races of plants, materially improve the texture of the soil, by loosening and separating the particles of earthy matter.

We avail ourselves of these useful properties of the grasses by introducing a grass crop into the series of crops of a rotation. By this means we not only obtain a crop of hay or a large quantity of the best sort of green fodder, but at the same time our land is greatly improved, and better fitted for the growth of the following wheat crop. The roots, stems, and leaves of the grasses, on being buried in the soil, gradually decay, and supply the succeeding wheat plants with all the materials they require for their growth, in a highly acceptable form. The artificial or temporary meadows cultivated for this double purpose are generally formed by sowing several

sorts of clovers and grasses with a corn crop,—generally barley. The grasses thus grown amongst the barley during the first year of their growth and the following summer, spring up and form a pasture, whose productiveness, of course, depends on the quality of the soil and the species of grasses sown.

The average composition of the commoner varieties of clover and other allied plants is as follows :—

AVERAGE COMPOSITION OF CLOVERS.

	Red Clover.	White Clover.	Yellow Clover.	Lucerne.	Sainfoin.	Vetch.
Water	80·640	83·65	77·570	73·41	77·320	82·16
Flesh-forming matters	3·606	4·52	4·481	4·40	3·512	3·56
Heat and fat-producing substances	13·784	10·26	15·949	19·11	17·438	12·74
Inorganic matters (ash)	1·970	1·57	2·000	3·08	1·730	1·54
	100·000	100·00	100·000	100·00	100·000	100·00

	Hay of Clover and Artificial Grasses.
Water	16·60
Flesh-forming constituents	15·81
Respiratory and fatty matters	37·63
Woody fibre	22·47
Mineral matter	7·59
	100·00

Comparison of Artificial Grasses and Clover Hay.—On comparing these results with those of the analyses of the natural grasses before quoted, we notice, that while the general composition is much the same in both cases, the artificial grasses contain, on the whole, more water, and, at the same time, more albuminous or flesh-forming principles than the natural grasses. The produce of artificial meadows is subject to the same causes of variation as those described as affecting the hay and grass of permanent pastures; and the remarks thereon offered apply with equal force to the present kind of produce.

The produce of pastures, of whatever kind, is either cut down and gathered in the form of hay, or is consumed by feeding off with cattle. In the former case, where the greater part of the produce is directly carried away, the land, of course, loses more of its essential constituents than when the same produce is consumed on the spot by cattle, and a considerable portion of it returned in the shape of manure. But even by this latter system, the soil is often exhausted to a greater extent than we should at first imagine; since on feeding off with cattle, the amount of essential substances permanently retained in the bodies of the animals, and, consequently, the extent to which the soil is exhausted, depends on the kind and condition of the stock employed in the operation. If the animals employed for this purpose are full-grown, and in tolerable condition, nearly all the nitrogen and mineral matter existing in the fodder will be returned to the soil in their excrements; and so far as the mineral substances and nitrogen are concerned, the soil would be in as good condition after the process as before, the only substance lost to the soil being that portion of its carbonaceous matter which has been converted into volatile products by the respiration of the animals, or that has been deposited in their tissues in the shape of fat. But in the case of animals that are lean or in bad condition, a portion of flesh-forming materials will also be permanently retained in their bodies, to make up the increase of flesh consequent on their arrival at a better state of body. In the case of young or growing stock, the loss sustained by the soil under these circumstances is still greater, as, in addition to the carbonaceous and nitrogenous materials, the soil will also have been deprived of the phosphates or bone-material required for the enlargement of the bones of the growing animals. Again, a corresponding loss of material will follow the pasturing of land by milch cows. The nitrogen and valuable mineral salts occurring so abundantly in milk will be formed at the expense of the

soil bearing the pasture on which the cows feed. Thus we perceive that whenever grass crops are fed off the land, the soil incurs a loss of fertilizing materials equivalent to the flesh, milk, or other animal produce formed through the instrumentality of the stock fed upon them. The same principles hold good with all other crops disposed of in the same manner.

The manures applied to grass land should be of a mild, slow-acting description, and all ammoniacal manures should be applied only in small doses, and evenly distributed; since anything like an overdose of ammonia tends to develop a coarse inferior sort of herbage. We notice this in the tufts of coarse grass that always spring up when the droppings of the larger animals are suffered to lie in masses on the pasture where they have been deposited; for the same reason, guano, unless much diluted by admixture with other substances, cannot be advantageously applied to grass land, as it is apt to excite an excessive development of grass of a rank, inferior description.

Sainfoin has before been noticed as a crop especially adapted for cultivation on thin light soils resting on the porous limestone rocks. The usefulness of sainfoin in soils of this character depends on its habit of sending its roots to great distances into the fissures of the subjacent rock, and extracting from it the small quantities of mineral fertilizing materials it generally contains. The valuable materials thus collected are brought to the surface and deposited in the various organs of the plant. On the conversion of the plants into manure, by feeding off, ploughing in, or otherwise, the surface-soil is enriched by the addition of these substances brought up from the depths of the subsoil.

Green Rye is a crop that has lately come into favour on account of the fine rich pasture it produces at a season when other kinds of grass are scarce. From the extraordinary rapidity of its growth, this species of

grass gives a pasture in a very short time. It is mostly employed for supplying the ewes and lambs with wholesome food during the spring months. Recollecting the use to which it is applied, we cannot be surprised that this crop should have gained the character of being a very exhaustive one: it must necessarily be so, when, as is usually the case, it is pastured by young animals.

Green Rape, White Mustard, and Rye, are each useful fodder crops; the former is particularly worthy of notice, since, in addition to a considerable proportion of flesh-forming materials and the ordinary respiratory principles, it contains a larger proportion of oil or fatty matters than is found in most other green crops. This fact clearly explains the well-known fattening qualities of rape as a food for sheep. The value of green rape as a fodder crop is highly estimated by some persons, who even recommend it to be occasionally cultivated in place of turnips, wherever the soil is good enough to admit of its vigorous growth.

Cabbage.—From the numerous useful qualities of this plant, it deserves to be more extensively cultivated as a fodder crop than it is at present. From the fact of its being richer in oil and nitrogenous matter than most other kinds of green food, and at the same time very succulent, its nutritive qualities are not to be wondered at. Cabbage is most valuable as a food for milch cows: it increases the quantity and quality of the milk, and the butter made from it is free of any unpleasant flavour. For other purposes, a more extended use of the plant is to be recommended.

The composition of this and some of the above-described plants, is as follows :—

COMPOSITION OF

	Green Rye.	Green Rape.	Cabbage.
Water	75·423	87·050	86·28
Nitrogenized substances (flesh-forming constituents)	2·705	3·133	4·75
Non-nitrogenized matters—			
a. Woody fibre	10·488	3 560	7·10
b. Fatty matters	0·892	0·649	
c. Respiratory substances	9·134	4·000	
Inorganic matters (ash)	1·358	1·608	1·87
	100·000	100·060	100·00

CHAPTER VIII.

ANIMAL PRODUCE.

HAVING now made ourselves acquainted with the composition of the vegetable produce raised on the farm, either for being carried to market and sold, or for home consumption as feeding material for the live stock of the farm, we must next consider the chemical principles involved in the conversion of this latter kind of produce, as grass, hay, roots, &c., into animal products, as beef, mutton, cheese, milk, &c. In order to understand the composition of these animal substances, and how they are formed in the animal system from the vegetable compounds consumed as food, it is necessary to glance at the general principles of the animal economy.

The operations involved in the process of nutrition have for their object the transformation of inanimate or dead matter into living substance. Without entering into anything like a detailed description of these operations, we may briefly describe them as follows :—

The body of an animal resembles a machine, in so far that by every movement of its parts or organs a certain amount of substance is worn away or destroyed. In the case of a machine, this loss by wear and tear is incessant while the machine is in motion, and sooner or later results in its destruction; but in the case of a living machine, as we may regard the bodies of animals, this loss of substance by exertion or wear is restored and replaced by new material, which is constantly provided for the purpose from the food consumed by the animal. Thus, in the bodies of animals, there are two operations constantly going forward,—the destruction and removal of old or exhausted materials, and the renewal or building up of new substance in place of that worn away. In the young animal this latter process prevails; and the quantity of new material being greater than that removed by exertion or exercise, every part of the system is strengthened and enlarged, and continues to increase in substance and bulk, until the animal attains full growth. These two operations being indispensable to the very existence of all descriptions of animals, it is clear that some means must exist, not only for supplying new material of every sort required to build up the several parts of the animal frame,—as the bones, flesh, hoofs, &c.,—but also for removing and carrying away the material which, having performed its office, is no longer of use in the system. These two primary operations are carried out in the animal organism by means of the functions called digestion, assimilation, circulation, respiration, excretion, &c. Without attempting to explain any of these vital processes, it will be well to trace the course of the materials consumed in the food to the places they occupy in the various organs and secretions of the animal system.

The food eaten by an animal, after mastication in the mouth, is received into the stomach, where, by the admixture of several secretions, its nourishing portion is changed, modified, and altered, so as to adapt it for use

in the animal system. Amongst these changes the most remarkable is the conversion of the insoluble nourishing principles into forms that are soluble in water, and that will admit of absorption. In the case of ruminating animals, a class to which most of our domestic animals belong, these chemical changes in the food are effected by a complicated system of stomachs, or rather divisions of the stomach, which need only be mentioned in this place. The altered food next passes into the intestines or bowels, where, by the further addition of the most important secretion of the body, namely, the bile, the separation of the nutritious from the non-nutritious substances is effected, and the former absorbed and collected by a series of vessels which finally convey the nourishing portion of the food to the blood; the useless matter—the woody fibre, &c.—of the food passes on and is expelled in the solid excrements. Having reached the blood, the soluble matter is carried by it to every part of the frame. The blood penetrates to every part of the animal system, and is the source from which every secretion is derived. Thus the bones, the flesh, the gristle, the milk, &c., are each prepared from the materials of the blood; each organ or tissue dips into the blood for the materials it requires for its sustenance or growth. To compensate for this impoverishment, the blood is enriched and its strength sustained by the constant addition of new material prepared from the food, as above described. The blood is also the vehicle by which the worn-out material is carried away, and conveyed to those organs whose special office it is to free and relieve the system of these waste substances; but such is the beautiful economy of nature, that while, on the one hand, useless materials are removed from a place where their presence is an encumbrance, they are by the same organs converted into compounds altogether as useful and indispensable in some other department of the system. Thus, for instance, the liver is one of the most important organs of the body,

inasmuch as, while it relieves the blood of a certain kind of impurity, at the same time it prepares from those impurities the bile, one of the secretions indispensable for the proper digestion of the food. Another of these organs, appointed for freeing the blood of its impurities and at the same time performing an indispensable office in the general economy, are the lungs. In these organs the blood, containing carbonaceous matter, is brought in close proximity to the atmospheric air, so that the combustible substances of the blood—the carbon and hydrogen—combine with the oxygen of the air, and form their respective oxides, which escape in the breath expired, as noticed in a previous chapter; at the same time, by this combination, heat is liberated, which, distributed by the circulation of the blood, quickly pervades the entire organs, and by its presence promotes the healthy action of all the animal functions. So important is the presence in the system of a due amount of heat or warmth, that a considerable portion of the natural food of animals consists of materials whose only purpose seems to be for supplying the lungs with respirable materials, or, in other words, for providing fuel for this slow process of combustion. The substances alluded to in the foregoing analyses, under the name of respiratory or heat-giving principles, belong to this class of bodies. An arrangement has been provided by nature for economizing this respiratory material; whenever more of these compounds are supplied to the blood than can be disposed of by oxidation in the lungs, the extra quantity is stored up in the shape of fat. Hence these respiratory compounds—as oil, sugar, starch, &c.—are also called fat-producing substances. From the above brief sketch of the operations involved in the process of animal life, we may arrive at the following conclusions:—

1. That as every movement of the animal body is attended by a waste of substance, and as this waste can only be made good from materials supplied in the food, it

follows that the greater the amount of exertion an animal undergoes, or the harder it is made to work, the more food it will require, and which, if not supplied, the health of the animal will be impaired.

2. That as the nourishment of an animal depends upon the amount of food digested, and not upon that eaten, it is clear that, however rich in nourishing principles a particular kind of food may be, unless it is also digestible it will be of little service in the animal system. Further, it is known that the digestibility of food varies with different kinds of animals; so that what may be wholesome food for one sort of animal may not be so for another. For this reason the value of feeding materials cannot always be judged of from their composition.

3. The food must contain materials capable of building up and renewing the muscles, bones, and tissues, and every part of the animal body wasted by exertion; it must also contain materials for sustaining the process of respiration and for producing fat. This latter substance, although invariably present in the animal system, is increased in quantity whenever the amount of respiratory materials supplied exceeds that required for the production of heat in the lungs: thus, the superabundance of respiratory food is stored up and preserved in the shape of fat until required.

In many respects the composition of the bodies of animals resembles that of plants. In each race of beings we find the same ultimate elements, in many cases arranged in the same groups;—the chief difference consists in the relative proportion of the two principal kinds of compounds so often referred to as nitrogenous and non-nitrogenous principles. In plants, the simpler carbonaceous or non-nitrogenous substances, as starch, woody fibre, &c., form by far the greater portion, and the choicer albuminous or nitrogenous compounds form but a small proportion of their bulk. In animals the reverse is the case: the bulk of animals consists of complex nitrogenous

compounds, while the simpler carbonaceous substances are present only in small quantities. As in the case of plants, the bodies of animals contain a large proportion of water (generally speaking, about 75 per cent.), and the dry substance consists of organic or combustible matter, and inorganic or mineral substances. The organic portion of animal matter is remarkable for the large proportion of nitrogen it contains; the mineral portion consists of the same materials which compose the ashes of plants, but differently arranged. It need scarcely be said that the following general remarks apply more particularly to the domestic animals usually reared on the farm.

The organic portion of animals, like that of plants, consists of a number of organized compounds or proximate principles; these compounds, together with certain of the mineral constituents, make up the various organs of which the animal structure is composed. Many of the proximate principles found in the bodies of animals are identical with those existing in smaller quantities in plants; indeed, as before hinted, plants prepare these compounds for the use of animals; for instance, there is a substance found in the blood of animals called fibrin, which is closely allied to the gluten of grain. Again, albumen is another constituent of the blood of animals, and is also found in the juices of vegetables; as in cabbage, &c. Another instance may be mentioned in the case of casein, or the curd of milk. This substance is chemically identified with legumen, the nitrogenous principle of pease, clover, &c. Besides these materials, directly derived from plants, there are found in the bodies of animals certain compounds peculiar to animal life: in most cases these are secondary products, or combinations produced from the partial destruction of the primary or albuminous compounds. Foremost amongst this class of animal compounds is gelatine, the material of which skin, horn, tendon, and the organic portion of bones, &c., are made. Another important con-

stituent of the animal body is fat. This compound is supplied ready-formed in feeding materials, and is also prepared in the animal organization from starch, sugar, and other respiratory materials of the food.

The inorganic or mineral portion of animals is remarkable for the large proportion of phosphate of lime it contains. This material exists chiefly in the bones, nearly two-thirds of which consist of this substance. The necessity of some earthy material to give strength and rigidity to the bones of the animal frame is obvious; but why phosphate of lime should have been selected for this purpose, we cannot surmise.

In less abundance, mineral substances are present in every part of the animal organism. In blood, flesh, nerves, &c., mineral salts exist as essential constituents.

As all the above-mentioned constituents of the animal frame, both organic and inorganic, are constantly being worn away and diminished by exertion and labour, and can only be renewed from the food, it is clear that to preserve an animal in a state of health, the food supplied to it must contain in sufficient quantity all the materials provided by nature for this purpose. If improper food is supplied, or, in other words, if any of these several materials are omitted, more or less derangement must ensue. Thus we may conclude that mixtures of substances containing a due proportion of each of the materials required in the animal economy, is the only kind of food upon which an animal will thrive, or, for any length of time, exist. Of course the composition of the food supplied to domestic animals may be varied to suit the purpose we wish them to perform. For instance, in the case of fattening cattle, the food supplied should consist for the most part of fat-producing materials, because little exhaustion of muscular structure is incurred by animals under these circumstances, and the greater part of the food supplied will be disposed of in the development of fat. On the contrary, in the case of working

horses, their food should contain a large proportion of flesh-forming materials, to make good the waste of substance consequent on the prolonged exertion these animals undergo.

Regarding animals merely as sources of beef, mutton, and other kinds of animal diet, they consist, for the most part, of bone, flesh, and fat. The first-named of these materials has already been sufficiently described; the two latter must now occupy our attention.

When the flesh or lean part of meat is washed in running water for a length of time, everything soluble will be removed, and a white stringy substance left. This substance is called fibrin, because it forms the greater part of the fibres of muscles. The flesh consists of various soluble matters distributed through this fibrous substance, the red colour being due merely to the blood left in the smaller vessels. The soluble substances of flesh constitute its most valuable portion when consumed as human food. The juice of flesh is found to contain several highly valuable mineral salts, albumen, and a peculiar principle called kreatin. Its general composition may be stated:—

COMPOSITION OF LEAN BEEF.

Water	78
Fibrin or gluten	19
Fat	3
	100

The cooking of meat should be done in a manner that prevents the loss of the highly-nutritious soluble matters. For this reason stewing is the most economical way of cooking meat; and boiling, for the same reason, the most wasteful. At the same time, by proper management, the loss of valuable soluble matters from meat by boiling may to a great extent be avoided by

recollecting the following facts, which may not be known to every one:—Amongst the soluble matters found in meat is albumen; this substance, which at ordinary temperatures is soluble in water, possesses the peculiar property of becoming insoluble, or of coagulating, by heating. We must all have noticed this property of albumen in the white of eggs, which consists almost entirely of this substance.

If meat is placed in cold water, and the whole gradually raised to the requisite temperature for cooking the meat, a great loss of nourishing materials is incurred; since the water will have an opportunity of extracting and dissolving a great portion of the soluble and more valuable constituents of the meat; but if the meat is placed at once in boiling water, the albumen contained in the outer layer of the meat will be coagulated, or become solid, and thus form a shell or case, which prevents the removal of the soluble materials contained in the inner portions of the meat. But, as is well known, this latter plan is incompatible with good cookery; the meat by this treatment is known to become "hard,"—a quality, of all others, that should be avoided in articles of animal diet.

The proper way of boiling meat seems to be to make a portion of the water boil in the vessel that is to receive the meat, then to add the meat, and boil for a few minutes, and now add more cold water, until the temperature of the whole is reduced to that best suited for cooking the meat: this temperature is about 160° of the thermometer.

The fat of animals is found to consist of two distinct kinds of fat, one of which is fluid, the other solid. The prevalence of one or other of these fats gives the distinctive characters to the different fats peculiar to particular species of animals, or to the different kinds of fat met with in various parts of the same animal; for instance, the fat of pigs contains a larger quantity of the fluid variety of fat than that of oxen or sheep: hence it is

softer and less firm. Again, the fat surrounding the kidneys of sheep and oxen, commonly called suet, is harder and more solid than the fat of other parts of their bodies. The fluid portion of fat is called oleine: this substance can be extracted from most natural fats by pressure. It resembles oil in its external properties, and is manufactured and used for the same purposes as oil, which indeed is merely a kind of fat in which the fluid part predominates. The solid portion of fat consists chiefly of stearine or of margarine. The former substance is the prevailing constituent of mutton and beef fat: it is prepared on a large scale from these substances for the manufacture of stearine candles. Margarine is the solid fat of butter, and constitutes the greater part of the fat of some animals, including man.

Having now described the general properties of the flesh of animals as supplied for human food, little remains to be said of the individual character of the flesh of particular species of animals; since these differences depend more upon the mechanical texture of the flesh than upon any difference in composition; yet, at the same time, the characteristic flavour of the flesh of different domestic animals might, no doubt, be traced to the presence of minute quantities of peculiar organic principles. The flesh of the same kind of animals is also subject to great variation, depending on the age, sex, condition, habits, and breed of the individual, and, to a greater extent, on the kind of food used in feeding. The value of meat as human food is regulated by the amount of nourishing principles it contains, as well as by the degree of facility with which these substances can be digested. The flesh of game generally possesses both these qualities in a high degree; and as, moreover, it yields, on cooking, a larger quantity of flavouring matter than most other kinds of meat, we are justified in supporting the high character of this description of animal food.

Milk, Butter, and Cheese.—As one would naturally

imagine, the secretion provided by nature and supplied by the mother to her offspring, corresponds in its composition to that of the young animal it is intended to nourish. Milk is particularly rich in every kind of material required for the development of the animal frame; it contains nitrogenous or flesh-forming substances, respiratory compounds, and the valuable mineral salts required for the formation of bones and other parts of the system. Moreover, all these substances are of the best description, that is to say, are of a kind that can readily be assimilated by the yet feeble organs of the young animal; and, further, the proportions of these constituents are adjusted to the wants and capabilities of the animal at this early stage of its existence.

COMPOSITION OF MILK AND CHEESE.

	Cows' Milk.	Asses' Milk.	Goats' Milk.	Chedder Cheese.	Skim-milk Cheese.
Water	87·02	91·65	85·54	36·0	44
Curd, casein, or cheesy matter	4·48	1·82	4·52	29·0	45
Fatty matter, or butter	3·13	·11	4·08	30·5	6
Sugar	4·77	6·08	5·40	..	..
Ash (bone material)	·60	·34	·46	6·5	5
	100·00	100·00	100·00	102·0	100

The milk of different animals varies as much in its external properties—its colour, taste, density, &c.—as in its composition. As the milk employed in the production of butter, cheese, and all other dairy produce is exclusively that of the cow, the following remarks apply more particularly to that kind of milk.

Milk is said to be a natural emulsion, or a fluid containing a number of fat globules diffused throughout its substance. As these particles of fat are insoluble in water, they give rise to the opaque white appearance common to all descriptions of milk. On standing, the greater portion of the fat globules rises to the surface and forms the cream. The globules of fatty matter are inclosed in little skins or shells; by violent agitation

these coverings are broken, and the fatty matter collects together in the form of butter. The composition of milk of course varies to as great an extent as any other kind of agricultural produce, being affected by the food supplied to the cow, the breed of the cow, its state of health, the treatment its receives, time that has elapsed since calving, time of milking, and a variety of other circumstances which need not even be mentioned here.

By referring to the foregoing table, we notice that the bulk of milk consists of water, the solid matter it contains being either suspended in it, as in the case of the fatty matter, or dissolved in it, as the casein or cheesy matter, sugar, and saline or mineral matter. We have already noticed the form in which the fatty matter or butter occurs in milk. The casein or cheesy matter of milk is a substance belonging to the natural group of albuminous or nitrogenous compounds so often referred to as flesh-forming materials. Casein resembles very closely the allied compounds already described, as gluten of wheat, albumen, legumin, &c. This substance is insoluble in pure water, but soluble in water containing alkalies, as potash and soda; hence the casein of milk is kept in solution by a small quantity of soda also present in the milk. If by any means we remove or overcome this alkaline substance, the casein is separated in an insoluble form. This operation takes place when milk is curdled. Thus we perceive that one of the purposes fulfilled by the mineral or saline constituents of the milk, is to keep the casein in solution. The primary office of the mineral substances is, however, to supply bone material to the young animal the milk is intended by nature to nourish. Hence, amongst other valuable mineral substances it contains a large proportion of phosphoric acid, the material, it will be remembered, so essential in the formation of bone.

The sugar of milk imparts to it the well-known sweet taste; but the sugar found in milk is somewhat different

from that prepared from the sugarcane, or from that belonging to fruits. Milk sugar, when separated from milk by suitable means, is a hard white substance, much less crystalline and sweet than ordinary sugar. Milk is an exceedingly unstable mixture. As it is intended by nature to be at once transferred from the receptacle of the mother to the body of the young animal, no provision is made for its preservation when removed from the living structure. Hence, by exposure, milk quickly undergoes spontaneous change; and if left for any considerable time, these changes are so extreme as to render it unfit for an article of diet. The first of these spontaneous changes is the turning sour or becoming acid, and a consequent curdling or separation of the casein or cheesy matter. This change is due to the formation of a peculiar acid called the acid of milk, or lactic acid, from the materials of the sugar of milk. This transformation in the sugar of milk is effected by the cheesy matter, which first undergoes alteration, and communicates the disturbing influence to the sugar; just as in the fermentation of beer or bread, it is the yeast that first sets up the tendency to change. This same acid is one of frequent occurrence in other mixtures than milk: the sour taste of brewers' grains or of raw malt, and the mash on which pigs and other cattle are fed, is due to the presence of this lactic acid, which is always found when vegetable substances of this description ferment. The simultaneous curdling of the milk with the formation of this acid is explained by the fact already pointed out in connection with the properties of casein. As casein is only soluble in the milk so long as an alkali is present to sustain its fluid form, it follows, that as the first effect of an acid formed in the mixture will be to neutralize this alkali, the curd or casein being now left without a supporter, must separate. The same effect can be produced artificially by the addition of any other acid; as vinegar, muriatic acid, &c. The separation of the curd is, however, most advantageously effected by the

addition of some substance which rapidly effects the separation of the cheesy matter, without exciting any other less desirable change: such a substance is rennet, the prepared membrane of the stomach of a calf.

Having now stated the general properties of milk and its contents, let us glance at the almost indispensable commodities prepared from it; viz., *butter and cheese.*

Butter consists for the greater part of the fatty matter of milk, but it also contains variable quantities of all the other substances found in milk. This is because the separation of the butter from the milk is always more or less imperfect. Hence we find in butter small quantities of water, sugar, cheesy matter, &c., accidentally present. By repeated melting, straining, and agitation with water, these impurities may be removed, and pure butter obtained. The fat of butter, like that of the bodies of animals, consists of a solid and fluid portion: the former consists of the fatty substance called margarine, the substance before alluded to as forming a portion of the fat of certain animals; the fluid portion consists of a variety of oleine. Besides these more abundant constituents, there are present smaller quantities of other fatty compounds, to which the pleasant taste and smell of fresh butter are due: it is to the formation of similar compounds, also, that the disagreeable qualities of rancid butter must be ascribed. The alteration and deterioration of fresh butter by keeping is chiefly induced by these impurities, especially the cheesy matter it contains. Hence the necessity of freeing the butter as completely as possible from these substances by washing, kneading, &c. To prevent or arrest these changes, it is common to impregnate the butter with various saline substances, amongst which common salt is most frequently employed. This substance acts in the same manner as when employed for the same object in the salting of meat; viz., by hardening and contracting the albuminous matter, and preventing its spontaneous putrefaction.

Cheese is essentially the casein or cheesy matter of milk, mixed with variable quantities of fatty matter and the other constituents of milk, more or less changed by incipient putrefaction. The richness of cheese, apart from the natural qualities possessed by the milk from which it is made, depends, in a great measure, on the amount of fatty matter or cream left with the milk before curdling. If cream predominates, the luscious but unstable cream cheese is formed;—if an additional quantity of cream is added to the natural milk, the more permanent and much esteemed Stilton is obtained. When the entire milk is used, such cheese as Chedder, double Gloucester, &c., results. If a portion or all of the cream is removed from the milk before being curdled, cheese of a corresponding quality is obtained.

The quality and richness of cheese are influenced by a host of circumstances; amongst which the character of the soil, the method of preparing, and the subsequent treatment, are prominent. The characteristic flavour of particular kinds of cheese is imparted by minute quantities of certain essences, produced by the mutual reaction of its constituents during the period of keeping. While many of these changes are understood, and can, to some extent, be regulated, the greater number are still enveloped in mystery, and at the present time are unexplored regions of Agricultural Chemistry.

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